AN EXAMINATION OF COMMERCIAL MOTOR VEHICLE HOURS OF SERVICE SAFETY REGULATION

DISSERTATION

Jason R. Anderson, Lt Col, USAF

AFIT-ENS-DS-16-S-025

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENS-DS-16-S-025

EXAMINATION OF COMMERCIAL MOTOR VEHICLE HOURS OF SERVICE SAFETY REGULATION

DISSERTATION

Presented to the Faculty

Department of Operation Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy in Logistics

Jason R. Anderson, BS, MBA, MS

Lt Col, USAF

September 2016

AFIT-ENS-DS-16-S-025

EXAMINATION OF COMMERCIAL MOTOR VEHICLE HOURS OF SERVICE

SAFETY REGULATION

Jason R. Anderson, BS, MBA, MS

Lt Col, USAF

Committee Membership:

Dr. Jeffrey. A. Ogden
Chair

Dr. William A. Cunningham
Member

Dr. Matthew A. Douglas
Member

Dr. Christine Schubert Kabban
Member

ADEDEJI B. BADIRU, Ph.D.
Dean, Graduate School of Engineering
and Management

AFIT-ENS-DS-16-S-025

Abstract

The Federal Motor Carrier Safety Administration (FMSCA) stipulates Hours of Service (HOS) regulations in order to minimize or eliminate fatigued truck driving, a major cause of truck-related accidents. This research examines the efficacy of HOS with three unique research approaches: 1) a typology classification model to indicate differences in HOS regulation from other safety regulations, 2) an exhaustive enumeration method utilizing the theoretical foundation of perishable inventory theory, and 3) a statistical analysis on accidents caused by or involving truck drivers. This research provides insight into similar Air Force Instructions regarding flight-time restrictions for pilots, which attempt to prevent flying while fatigued. This research demonstrates that these types of restrictions do not directly measure fatigue and that they are subject to various unintended consequences.

Classification is a tool that can be used to conceptually understand the differences in regulations. Using disjointed incrementalism as its theoretical foundation, this research proposes a new typology, a specific form of classification, and utilizes this typology to examine a sample of 14 commercial motor vehicle safety regulations qualitatively and quantitatively. This approach offers explanative insights into preferred types of regulations as well as predictive insights into how regulations change over time.

This research also utilizes an Exhaustive Enumeration technique in order to find optimal discrete values for the various different HOS regulations. For example, this research found that drivers could accumulate 28.6 percent more average daily driving

hours in 2012 than in 2014 due to the recent change in HOS regulations. Not only are the HOS regulations restricting the amount of truck driver hours, but there has also been an increase in the amount of HOS regulatory changes. Eleven of the 23 HOS regulation changes have occurred since 2003. This ever-changing regulatory environment has many safety implications to the truck driving industry. Perishable inventory theory is used to understand how companies and truck drivers operate within this regulatory environment. This theoretical foundation provides a unique view on possible unintended consequences created by some of the recent HOS regulations.

In July 2013, the Federal Motor Safety Carrier Association (FMSCA) revised its Hours of Service (HOS) regulatory policy, which restricts the number of duty and driving hours a truck driver can operate. The revision changed the unlimited restart provision by restricting it to 1 restart per 168 hours (1 week) and added that the restart must span two consecutive 1 am to 5 am periods. Lawmakers suspended these two aspects of the restart provision in the Consolidated and Further Continuing Appropriations act on December 16, 2014 until more analysis was completed on the efficacy of these regulations due to unintended consequences that allegedly negatively affected motorist's safety. Countering truck driver fatigue is an important issue and an extremely difficult task because of the many confounding aspects that can cause fatigue. The new regulation set forth in July 2013, was supposed to lessen fatigue and thus reduce accidents caused by truck drivers. The current HOS regulation was in place for approximately 16 months, producing enough data for a statistical analysis of its effects on truck driver safety. This research found that by comparing truck driving safety data prior to the change in July of 2013 (the unlimited restart provision) to truck driving safety data during the enactment of the 1 restart per 168-hour restriction and 1 am to 5 am provision, the percent of accidents caused by truck drivers did not decrease. Furthermore, this research found that the HOS changes implemented on July 1, 2013 have not led to a change in the continuing downward trend in accidents involved and caused by truck drivers. These results suggest that other factors appear to be linked to motorists' safety, rather than the updated HOS regulation.

Acknowledgments

I want to sincerely thank the entire AFIT program for providing me the opportunity to undergo this dissertation effort. Foremost, I want to extend my utmost thanks and appreciation to my research advisor, Dr. Jeffrey Ogden. I want to also thank my committee members, Dr. Cunningham, Dr. Douglas, and Dr. Schubert-Kabban for all of their help and guidance.

During this program, we had two additions to our family and I want to say thank you to my wife for her support at home and in my work. I also want to acknowledge and thank my wonderful sons. I love you all so much.

Jason R. Anderson

Table of Contents

List of Figures

List of Tables

List of Equations

EXAMINATION OF COMMERCIAL MOTOR VEHICLE HOURS OF SERVICE SAFETY REGULATION

I. Introduction

Background

Although trucks are one of five main modes of logistics (air, maritime, rail, and pipelines being the others), they interface with logistics more than any mode. In fact, 81.9% (ATA 2011) in terms of value and 60.1% of volume of U.S. domestic goods are shipped with trucks (Dobbins, 2007). Trucks are critical to the shipment and movement of goods mainly in part due to the flexibility they provide. This flexibility is the result of the vast availability of roads, as well as the large number of trucks and truck drivers. There are approximately 3.5 million truck drivers and 26.4 million trucks registered (ATA 2016), and about 1 of 15 workers in the country are employed in some aspect of the trucking industry (All Trucking 2016).

The truck industry is vital to the US economy, and if the truck driving industry is restricted, it will have great impacts to the economy and to our society. For example, trucks are primarily responsible for moving goods for the food industry, and if trucks were halted for a mere three days there would be food shortages across the country (McKinnon 2006).

While trucks are important for delivering goods, they are also responsible for accidents involving other motorists. Accidents involving trucks occur more often when truck drivers have been awake or on duty for long periods (Soccolich et al. 2013; Hanowski et al. 2007; Jovanis et al. 2011; Braver et al. 1999). This safety concern brings about legislation that restricts the truck driver’s duty and driving time. Balancing safety (through restricting truck driver’s hours of operation) and maximizing the logistical capacity of trucks and truck drivers is a challenge.

There have been both economic and safety regulations in the truck industry. Hours of service (HOS) is one of the safety regulations and is the focus of this research HOS restricts the number of hours that a truck driver can operate as well as mandate the number of off-hours prior to coming back on duty in order to reduce fatigue and accidents involving trucks. Pritchard (2010) found that there are about 5,000 fatal crashes involving trucks per year resulting in social costs greater than 32 billion dollars. Many of these accidents have been caused by fatigued truck drivers, which may have been prevented with proper rest and truck driver awareness (Quan et al. 2015). The Federal Motor Carrier Safety Administration (FMSCA) has instituted measures that restrict the driving and duty hours of truck drivers to promote safety and minimize any negative economic impact on the commercial motor vehicle industry.

Research has demonstrated how fatigue leads to increased accident rates by decreasing reaction time, disorientation while driving, and overall impaired performance (Williamson et al. 2011; Min 2009a). The majority of research has examined the factors that lead to fatigue. Research has found an increase in accident rates involving trucks from 50 percent to 200 percent in the 10th and 11th hour; and statistically significant accident rates after the 8th hour (Abrams et al. 1997; Hanowski et al. 2011; Kaneko & Jovanis 1992; Jovanis et al. 2011). Research has also found contributing factors to fatigue and accident rates such as the number of breaks and break duration (Blanco, Hanowski & Olson 2011; Chen & Xie 2014b), sleep habits (Gander et al. 2006), carrier scheduling practices (M. Crum & Morrow 2002), schedule induced practices (Beilock 1995; Soccolich et al. 2013), cargo type (Retzer et al. 2013), loading and unloading (Shibuya et al. 2010), obesity and sleep apnea (Anderson et al. 2012), time pressures (Kemp et al. 2013), long-haul vs short-haul (Friswell & Williamson 2013), age (Summala & Mikkola 1994; Duke et al. 2010), and many other factors that can be seen in both Figure 1 and Figure 2.

Ironically, one factor that has not been well researched is the factor that attempts to regulate the fatigue of truck drivers—HOS regulation.

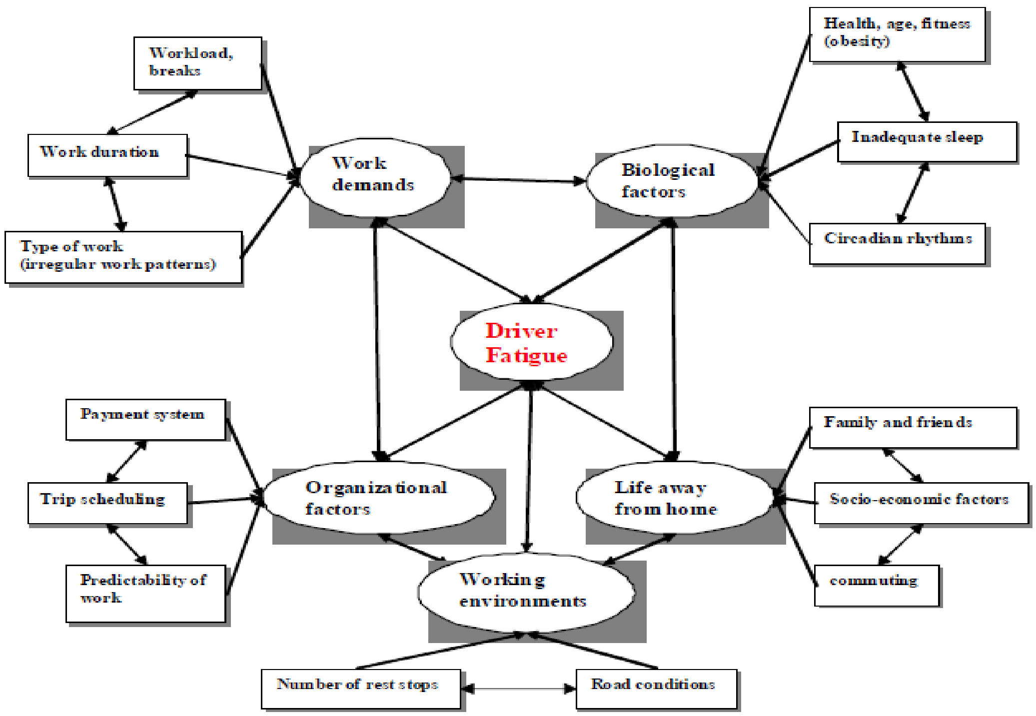


Figure 1 Factors Affecting Driver Fatigue (Min, 2009)

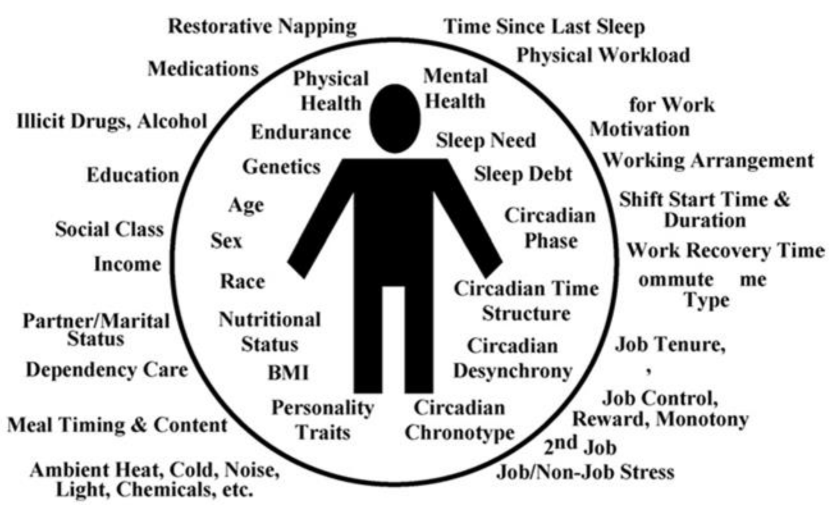


Figure 2 Potential Endogenous and Exogenous Factors on Fatigue (L. Di Militia et al., 2011)

Although it is clear that driver fatigue is dangerous and has been linked to higher accident rates (Dinges 1995; Mackie & Miller 1978; Williamson & Friswell 2013; Summala & Mikkola 1994; Zhu & Srinivasan 2011), the effectiveness of HOS regulatory policy on reducing fatigue and making roads safer is still unclear (Arnold et al. 1997; Min 2009b). Research has found that many drivers actually begin their driving periods fatigued, indicating that HOS may restrict the number of operating hours but does not directly reduce fatigue or ensure alert truck drivers (Abrams et al. 1997). It is also possible that HOS has resulted in less safety for truck drivers and motorists.

HOS may have unintended consequences. As an example, research found that HOS safety regulation increased congestion at peak times putting both motorists and truck drivers at more risk (Dingus et al. 2006; Downs 1992; Bucklew 2011; Ferro 2014; FMSCA 2010). Similarly HOS provisions may have made motorists less safe due to circadian rhythm swaps (Ferro 2014), which has been shown to increase fatigue (Abrams et al. 1997; Arnold et al. 1997; Arrow et al. 1996; Sando et al. 2010). Research has also found that 14 percent of truck drivers were found to avoid known check stations (deviating from their route by up to 160 miles) thereby driving on less-safe rural roads (Taylor et al., 2000).

Although scarce, there are examples in western civilizations that contrast the difference between regulated and unregulated states providing further evidence for the previous arguments. Arnold et al. (1997) discussed unregulated drivers in Australia while Williamson et al. (1992) discussed regulated drivers in Australia. Comparing these two articles provided an interesting perspective regarding the potential problems with HOS regulations in Australia (see Table 1). These differences suggests that regulations result in less sleep to drivers, more traffic to society, higher perceptions of fatigue, longer working hours at varying times of the day, and a higher incident of drug use. These results were also confirmed by Dingus et al., (2006), who found that unregulated drivers (Intra- versus Inter-state) slept more than regulated drivers did.

Table 1 Regulated versus Unregulated Drivers in Australia

	Arnold et al.	Williamson et al.
	Unregulated	Regulated
Prior Night of Sleep Before Journey	8.25	7.5
Perceive fatigue is an issue for themselves	10%	28% to 35%
Perceive fatigue is an issue for the industry	39%	78%
Coontributions to fatigue		Heavy City Traffic
Loading Unloading as a problem with fatigue	33%	47%
Driving at dawn causing fatigue	21%	56%
Long driving hours cause fatigue	38%	49%
Lack of sleep during the trip	40%	32%
Drugs	16%	32%

More recently and in the U.S., there have been conflicting claims about the effectiveness of recent HOS regulation changes. Some trucking unions and some members of Congress have claimed negative safety implications due to prolonged traffic congestion during daytime hours and increased fatigue (Ferro 2014; Short 2013). Conversely, legislative branch members and research has claimed that the HOS revision has decreased accidents, reduced damage, and most importantly, saved lives (Ferro 2014; Chen et al. 2015; FMSCA 2010).

Since there is little research regarding the HOS regulations as a possible factor contributing to fatigue and other possible negative safety implications, this research attempts to fill this gap. This research provides three different approaches to understanding HOS regulatory impact on safety.

This research approaches this complex problem by researching three main topics (see Figure 3). First, the regulation is inherently indirect in its approach because it does not target fatigue but rather duty hours. Second, as the regulation changes it alters the hours and capacity of truck drivers dramatically, creating many other possible unintended incentives. Third, since it is an indirect policy and incentives may change, it is possible that there will be unknown safety consequences from this policy--shown as unintended consequences.

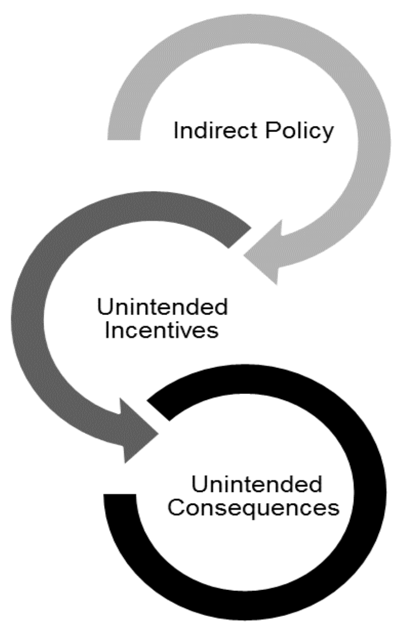


Figure 3 Hours of Service Safety Construct

To elaborate more on the first point, HOS does not directly manage fatigue of truck drivers. Therefore, it is entirely possible that a truck driver follows the rules but still violates the intent of the law. This information is not new, but has not changed this regulation from indirectly managing fatigue. An example is a FMSCA (2000) report quotes an ICC official who objected to the proposed HOS regulation in 1937:

> We have no control over the manner in which a driver may spend his time off-duty, although some of his spare time activities may tire him as much as any work would do. We can only emphasize, by this comment, the responsibility which is the driver's own to assure himself of adequate rest and sleep, in the time available for this purpose, to ensure safety of his driving, and likewise the employer's responsibility to see that his drivers report for work in fit condition (ICC, 1937).

This quote reveals that HOS is only looking at one factor that relates to fatigue. This implies that this regulation may be very different from other safety regulations in the trucking industry. Thus, the first paper, or chapter 2 of this dissertation, attempts to understand how HOS is different from the other regulations by creating, utilizing, and empirically testing a typology classification construct.

To further expand on the second point; changes in HOS regulations restrict or increase capacity for truck drivers. Restricting or increasing the number of hours a truck driver can operate will have corresponding logistical impacts to a lean supply chain. The number of truck drivers, tractors, distribution centers, the amount of inventory needed for a given service level are only but a few of the possible changes that may occur to the supply chain. It is important to understand the complex changes that can occur to the supply chain and the truck driving industry when HOS regulations are modified. This is accomplished in paper 2, or chapter 3 of this dissertation, which details how perishable inventory theory and its associated tactics can be used to understand the complex safety consequences of an ever-changing HOS regulatory body.

The third point of this dissertation is to determine if this regulation has increased safety or decreased safety for truck drivers and motorists. This is a difficult problem due to the dates of the HOS changes not coinciding with the annual data, and reports indicating if the motorist or truck driver was at fault. In order to overcome these obstacles, data was used from an Ohio database. From this data, it was possible to discover the number of accidents involving and caused by truck drivers regarding property damage, injury, and fatal accidents. Utilizing regression, parametric, and nonparametric techniques, this research was able to examine the safety efficacy of HOS in Ohio. The Ohio data was also extrapolated to provide for an analysis on truck driver safety in the U.S. From this extrapolation, more information was revealed regarding the accuracy of FMSCA's predictions.

The last chapter of this dissertation provides concluding remarks regarding this research. It will also provide the contributions from this research, and possible implications to the Department of Defense (DoD).

II. A Typology Classification Approach to Exploring Differences in Commercial Motor Vehicle Safety Regulations

Abstract

Classification is a tool that can be used to conceptually understand the differences in regulations. Using disjointed incrementalism as its theoretical foundation, this research proposes a new typology, a specific form of classification, and utilizes this typology to statistically examine a sample of 14 commercial motor vehicle safety regulations. This approach offers explanative insights into preferred types of regulations as well as predictive insights into how regulations change over time.

Introduction

The Federal Motor Carrier Safety Administration (FMSCA) is charged with regulating the safety of the commercial motor vehicle (CMV) or trucking industry. Safety regulations governing the CMV industry have existed since the publication of the first code of federal regulation in 1938. Safety regulations include hours of service (HOS), which stipulates the driving and duty time limits for truck drivers.

HOS has changed frequently since 2000 creating a discussion involving legislators, researchers, and the trucking industry regarding what regulations are needed to prevent fatigue-related accidents. This research does not attempt to provide an optimal regulation for HOS or the factors that may lead to fatigued truck drivers, but rather uses a classification methodology to understand differences in the HOS safety regulation from other CMV safety regulations.

This research provides a descriptive, explanative, and predictive model for regulation types. Each regulation has unique characteristics that can be classified into a two-by-two typology representing four *types* of regulation. These *types* of regulations are: 1) subjective-direct, 2) subjective-indirect, 3) objective-direct, and 4) objective-indirect. Classifying regulations into this conceptual model enables a descriptive comparative analysis of regulation *types.*

Since a specific regulation changes over time and those changes are generally viewed as improvements, it follows that the change in associated classification *type* would also be viewed as an improvement. Thus, *type* changes help explain the *type* most suitable for a specific regulation at a specific time.

This research also provides predictive power to the eventual *type* of a regulation given its initial *type* classification. A predictive model is created by analyzing how a change in a regulation can potentially lead to changes in the classification type.

Each classification *type* has associated characteristics. The characteristics of the regulation *type* are 1) character count, 2) section count, and 3) time between changes. The conceptual model can therefore be validated empirically by utilizing parametric and non-parametric testing techniques to test for differences in characteristics among each *type*.

To better understand regulation changes over time, the theory of disjointed incrementalism is introduced. This theory underscores that regulation change occurs incrementally due to political feasibility, and occurs disjointedly due to decision-makers' constraints of time, analytical ability, and fragmented goals (Lindblom 1959).

This research is broken down into five sections. The literature review details previous research in the field of classification. The methodology and analysis sections discuss the clear and repeatable analysis used in this research. A discussion of the results and possible future research directions concludes the article.

Literature Review

Creation of Typology Classification

The classification of policy provides a theoretical framework needed to better partition differences in policy creation and implementation. This framework enables organization and linkage to predictable patterns of policy and implementation in regards to the expected political and social behaviors that may arise (Smith 2002; Schneider & Sidney 2009). Mitchell et al. illustrate that classification is a critical prerequisite for understanding the lineage of decisions regarding policy (1985). They also suggest meaningful hypotheses can come from segmenting government policies, leading to conclusions on policy performance. They conclude that the classification of policy does not lead to successful policy, but that it is a prerequisite for it.

Classification is the foundation for language, speech, math, data analysis and the understanding of concepts (Bailey 1994). For instance, the concept of a vegetable begins and ends with the classification of similar or dissimilar ideas (Bailey, 1994). This classification process can also be used for policies implemented by the government, which have the ability to affect the human race for generations (Schneider & Sidney 2009).

Classification of policy is not only important but also challenging (Smith 2002; Lowi 1972; Bailey 1994; Schneider & Ingram 1997; DeLeo 2015; Lowi 1964; Anderson 1997; Drescher et al. 2011) for numerous reasons. Three of these reasons are: 1) dimension scaling, 2) ensuring homogeneity within the policy *type* and heterogeneity amongst the policy *types*, and 3) clear definitions for classification (Bailey 1994; Kluge 2000).

Dimension scaling is necessary due to the exponential number of policy *types* that can be created. For example, a four dichotomous typology has 2^4 or 16 *types* and a four trichotomous typology would have 3^4 or 81 *types*. More *types* may create clearer differences and heterogeneity amongst the *types*, however the model's complexity may lose usefulness due to its complexity (Bailey 1994).

Creating a simple typology may provide a useful conceptual and descriptive model as long as its *types* can be clearly differentiated. Homogeneity within the *type* and heterogeneity among the types creates the most useful typology but requires specific and repeatable classification techniques (Kluge 2000; Barton 1955).

Smith (2002) discussed that a typological approach can be powerful but prone to classification error and therefore not repeatable. He discusses how loose definitions regarding subjective classifications are one of the most common errors within classification research that leads to questionable and non-repeatable results.

Policy and Regulatory Design

Research regarding classification of policy *types* and creation of typologies within the field of CMV policy does not exist, based on the literature search. However, there is a plethora of research within the social sciences that can be drawn from to bridge this research gap in the CMV policy field.

In policy design, Schneider and Sidney (2009) suggest the first step is the problem definition and goals to be pursued. The goal of the regulation may be straightforward, but the implementation of the policy may not be because of the inability to measure the goal—leading to an *indirect* policy. For example, the HOS regulation intends to eliminate driving while fatigued (Federal Motor Carrier Safety Administration 2016); however, the regulation only restricts the duty and driving time, which have been shown to be factors in fatigued driving (Brown 1986; Torregroza-Vargas et al. 2014; Williamson et al. 1992; Williamson et al. 2011); but there are also many other factors that contribute to truck driver fatigue. A few of these fatigue factors that are not regulated by HOS are: multi-day driving patterns (Kaneko & Jovanis 1992); starting fatigue level (M. R. Crum & Morrow 2002); driving time of day (Blower & Campbell 1998); miles driven (Lyman & Braver 2003; Joshua & Garber 1990; Jovanis & Chang 1986); truck driver health (Anderson et al. 2012; Stoohs et al. 1994), traffic congestion (Taylor & Dorn 2006); truck driver obesity (Anderson et al. 2012; Stoohs et al. 1994); distracted driving (Olson et al. 2009; Hanowski et al. 2005); stress, health and narcotics (Taylor & Dorn 2006; Hartley & Hassani 1994; Crouch et al. 1993); scheduling (M. R. Crum & Morrow 2002; Min 2009b); and attitudes (Douglas & Swartz 2009). Thus, HOS may have different results than other safety regulations because it is not directly regulating or measuring fatigue.

Schane (2002) examines the legal words found in laws and finds that some are not always clear; leading to the law being understood in more than one way. Veenhoven (2002) discusses these vague or *subjective* words and their importance in social policy. *Objective* measures focus on the facts while *subjective* measures on the soft facts. He states that *subjective* indicators enable a *subjective* measurement and may require change for clarity. However, *subjective* measures can sometimes provide the regulations' intent or goal, while *objective* measures tend to be more myopic by looking at sum-scores. The combination of both *subjective* and *objective* regulations may lead to a more comprehensive regulation that can be objectively enforced by numbers and clear guidelines, while also providing the goal or intent of the regulation.

Disjointed Incrementalism

The theory of disjointed incrementalism gives emphasis to the capacity of legislatures, their method, and the eventual acceptance of policy (Lindblom 1959). The first point, that this theory suggests, is that the capacity of legislators is limited mainly due to time constraints and limited expertise. These limitations can lead to *disjointed* policy. The next main point from this theory is the method by which policy is created, which emphasizes the *disjointed* and *incremental* aspect. Generally, when there are agreed upon values, the ends justify the means. When there are conflicting values (which occurs due to special interests groups, concerned citizens, and legislatures), the means and ends are simultaneous chosen for expediency and compromise. This method may lead to *disjointed* policy through exemptions and other aspects of the regulation and *incremental* changes in policy, which meet the aspirations of society and legislators constituents while minimizing political risk.

Method

The first part of the methodology details the conceptual model (typology) that was created. Dimension scaling was accomplished to keep the typology simple (Bailey 1994). Two monothetic dimensions were used to create a fourfold typology. The four *types* are subjective-direct, subjective-indirect, objective-direct, and objective-indirect. Subjective and objective were chosen due to the prevalence of ambiguity and misunderstandings that occur in laws and regulations (Schane 2002). The dimension of direct and indirect were used due to the varying level of agreement that sometimes exist between the means (regulation) and ends (goals) of the regulation (Montgomery 1990; Nicoletti & Scarpetta 2003; Lindblom 1959).

Bailey (1994) stated that the secret to classification is the ability to ascertain and differentiate the fundamental characteristics of the phenomenon studied. In our research, the clear and comprehensive definitions were critical to the success of this research and were developed after consulting with a lawyer, a compliance manager, and other researchers. The definitions utilized for this research are as follows:

- Objective: The typical prudent person would understand this rule and know with reasonable certainty when a situation was in or out of compliance with the stated rule.
    - Example: Drive no faster than 45 mph
- Subjective: Discretion and interpretation is required to act in accordance with this rule. The typical prudent person would have trouble clearly classifying whether a specific situation was in or out of compliance. Frequently, reasonable arguments could be made in support of either compliance or noncompliance for a given scenario.
    - Example: Drive safely
- Direct: What is governed, measured, or stipulated by the rule is highly correlated with the desired or undesired behavior. Disobeying the rule naturally and consistently leads to predictably unfavorable outcomes regarding the regulation's desired goal.
    - Example: No drinking of alcohol 10 hours before or while operating a vehicle (Direct because the regulation is restricting the direct act of being under the influence of alcohol)
- Indirect: What is governed, measured, or stipulated by the rule may or may not be unequivocally correlated with the desired or undesired behavior. A prudent person can cite plausible and common scenarios in which following the rule will not lead to the desired outcome.
    - Example: No going to a bar before or while on duty (Indirect, because the regulation is restricting a behavior that may or may not lead to being under the influence of alcohol)

Certain assumptions are also needed in order to classify these regulations. First, this research assumes that some regulations are not fully comprehensive or exhaustive and a classification of a regulation does not depend on whether the regulation captures every possible scenario. Second, this research assumes that the numbers or limits stipulated by the regulations are correct. This research does not argue whether .04-blood alcohol content (BAC) is the right value, but rather whether a value is provided and understood. Third, this research assumes that some regulations may require a capability of enforcement that is not likely to occur due to limitations of enforcing agents.

Hein Online was the primary instrument used to collect the data on the regulations. Regulations were digitally captured for the period of 1938 to 2016, which corresponds to the beginning of regulations on the commercial motor vehicle (CMV) industry. The Code of Federal Regulations (CFRs) and list of sections affected were used to capture the dates and associated regulation changes. Due to title number changes and limitations on CFRs before 1961, the Federal Register (FR) was also searched for any final ruling on the specific regulation. The FR also provided relevant information and discussion during the hearing or changing of the regulation that aided in the rationale for the regulatory change.

Fourteen different CMV safety regulations were chosen from dissimilar CFR parts under title 49 in order to gather a wide variety of regulations to analyze. The 14 regulations dealt with the following issues 1) Brake Performance, 2) Sleeper Berth, 3) Inspection, Repair, and Maintenance, 4) Tires, 5) Hazardous Conditions, 6) Alcohol Prohibition, 7) Ill or Fatigued Drivers, 8) Necessary Driving Knowledge and Compliance of the Regulations, 9) Needed Skill and Experience, 10) Drugs and Other Substances, 11) Hearing Requirements, 12) Eyesight Requirements, 13) HOS, and 14) Safe Loading Procedures. Any associated change to these regulations or subparts of these regulations were documented. Documenting this data enabled an analysis of the level of change (substantial or non-substantial), the character and section count involved the change, the date of the change, and the reason for the change (if available).

Non-substantial changes were based on minor modifications to references, titles, or parts of the regulation. An examples of these non-substantive changes include changing him to him/her or the driver, and "motor vehicle" to "commercial motor vehicle driver" (Federal Motor Carrier Safety Administration 1995). Substantial changes occurred when the regulation added or deleted sections, or changed wording.

The initial regulation and any associated substantial changes were provided to four logistics doctoral students for classification. Based on the results of this pretest, minor revisions were made to the definitions, instructions, and formatting prior to giving it to the classification team.

The specific regulations and the chronological changes were provided to four academics on the classification team. The team classified 275 changes that occurred in the 14 regulations between 1938 and 2016. The change in part of the regulation as well as the entire regulation was classified based on the definitions provided. To assess inter-rater reliability, pairwise percent agreements and Cohen's Kappa statistics were calculated (Fleiss 1973; Cohen-Mansfield & Werner 1997). Kappa values range from 0 to 1 with the closer to 1 indicating a closer agreement of classification *types* from the team (Fleiss 1973).

After the team classified the regulation and the subparts of the regulation into the specific *types*, a statistical analysis was completed. Measurements including the mean time a regulation stayed a certain *type*; the probability of a regulation changing from one *type* to a different *type*; and if information was available, the circumstances that led to the change in the regulation was analyzed.

An empirical analysis was also conducted after the regulations were classified into *types* in order to strengthen this typology construct. The characteristics of the typology that were used were character count, growth in both characters and sections over time, number of substantial changes, and probability of change to a different *type*. To examine differences between *types*, averages, standard errors and deviations, and Analysis of Variance (ANOVA) testing was conducted followed by the post-hoc Fisher's Least Significant Difference (LSD) pairwise comparison. ANOVA parametric assumptions were met for character and section count, which assessed normality using the Shapiro-Wilks test (Razali & Wah 2011); constant variance was assessed using the Bartlett test (Levene 1960); and independence by time was assessed via the Durbin-Watson test (Kanlayasiri & Boonmung 2007). However, for number of substantial changes, parametric assumptions were not met. Consequently, non-parametric tests were conducted using the Wilcoxon Signed Rank test (Hollander et al. 2013).

Analysis

The Cohen's Kappa value regarding the inter-rater reliability of the classification of regulation into specific *types* was 0.8 with an average pairwise agreement of 86.5 percent. This kappa value falls at the top of the substantial agreement range and just shy of almost perfect agreement (Landis & Koch 1977).

Of the regulations that existed in 1938, 11 were classified initially as subjective-direct, 1 as objective-direct, 2 as not existent yet (--), and 1 as objective-indirect (see Table 2). The objective percent and direct percent are shown for each regulation. A general trend was that each regulation became more objective over time. The number of sections and characters is listed underneath the percentages and provides information about the size of the regulation changes. The general trend with regulation size was an increase in character count and sections, which was correlated with the shift to more objective regulation *types*. Of the regulations that began as subjective-direct, nine became objective-direct and four ended as subjective-direct. The two regulations that began as objective-direct remained that *type.* Hours of service regulation was the only regulation classified as objective-indirect and it remained this *type*.

Overall movement of regulation *types* are shown in Figure 4. Subjective-direct regulations had a 71.5% chance of staying subjective-direct upon a substantial change to the regulation and a 28.5% chance of changing *type* to objective-direct. Subjective-direct regulatory *types* changed at a rate of 23.5 years and a standard deviation of 13.8 years. This *type* changed to an objective-direct *type* at a rate of 28.7 years with a standard deviation of 5.3 years. Objective-direct regulation *types* changed at a rate of 19.5 years and a standard deviation of 12.2 years. Indirect-objective regulation *types* changed at a rate of 7.09 years and a standard deviation of 7 years.

Table 2: Regulation by Year Objective / Direct Percent and Characteristic (Section count, Character count)

Date	1938	1940	1950	1960	1970	1980	1990	2000	2010	2016
CFR	1	3	15	25	35	45	55	65	75	81
Brake Performance	63%/100% (3,853)	75%/100% (3,1199)	75%/100% (3,1223)	63%/100% (3,971)	100%/100% (6,954)	100%/100% (10,1617)	100%/100% (10,1617)	100%/100% (10,1617)	100%/100% (11,2240)	100%/100% (11,2240)
Sleeper Berth	--	--	--	70%/78% (12,3852)	70%/78% (12,3983)	62%/78% (20,3716)	62%/78% (21,3571)	62%/78% (21,3571)	62%/78% (21,3571)	62%/78% (21,3570)
Equipment Inspection	--	%/100% (2,206)	%/100% (2,206)	71%/79% (6,1414)	71%/79% (7,1447)	77%/91% (12,1909)	77%/86% (11,1737)	77%/82% (10,1776)	75%/84% (10,2003)	75%/84% (10,2003)
Tires	25%/75% (2,199)	25%/75% (2,207)	25%/75% (2,207)	33%/100% (4,919)	100%/100% (6,915)	92%/98% (14,2494)	93%/93% (16,3016)	94%/94% (17,1821)	93%/94% (18,3191)	93%/94% (18,3191)
Cargo Inspection	0%/100% (2,199)	0%/100% (2,207)	0%/100% (2,207)	0%/100% (4,919)	17%/100% (6,915)	48%/98% (14,2494)	48%/98% (16,3016)	48%/98% (17,1821)	48%/98% (18,3191)	48%/98% (18,3191)
Hazardous Conditions	0%/100% (2,293)	0%/100% (2,326)	0%/100% (2,326)	0%/100% (2,326)	0%/100% (2,668)	0%/100% (2,668)	0%/100% (2,668)	0%/100% (2,725)	0%/100% (2,725)	0%/100% (2,728)
Impaired Driving	0%/100% (2,461)	0%/100% (2,474)	0%/100% (2,465)	0%/100% (2,465)	0%/100% (2,459)	0%/100% (2,643)	0%/100% (2,643)	0%/100% (2,708)	0%/100% (2,708)	0%/100% (2,709)
Knowledge	0%/75% (2,358)	0%/75% (2,334)	0%/75% (2,335)	0%/75% (2,335)	0%/100% (2,187)	89%/100% (12,3616)	89%/100% (12,3616)	0%/100% (2,187)	0%/100% (2,187)	0%/100% (2,187)
Experience	13%/100% (3,303)	13%/100% (3,329)	13%/100% (2,324)	13%/100% (2,324)	13%/100% (4,368)	76%/93% (20,3386)	76%/93% (20,3386)	76%/93% (20,3522)	76%/93% (20,3522)	76%/93% (20,3516)
Narcotics	25%/75% (2,79)	25%/75% (2,166)	25%/75% (2,159)	25%/75% (2,159)	25%/75% (2,159)	68%/100% (8,990)	75%/100% (9,1024)	75%/100% (9,1045)	75%/100% (9,1045)	75%/100% (9,1045)
Alcohol	25%/100% (2,186)	25%/100% (2,247)	25%/100% (2,247)	25%/100% (2,247)	25%/100% (2,348)	65%/95% (8,1009)	84%/93% (15,2580)	90%/94% (17,2717)	90%/94% (17,2735)	90%/94% (17,2735)
Hearing	0%/100% (2,35)	0%/100% (2,35)	0%/100% (2,35)	0%/100% (2,35)	75%/100% (2,122)	75%/100% (2,434)	75%/100% (2,434)	75%/100% (2,434)	75%/100% (2,434)	75%/100% (2,434)
Eyesight	0%/100% (1,151)	100%/100% (1,292)	100%/100% (1,292)	100%/100% (1,292)	100%/100% (1,375)	100%/100% (1,470)	100%/100% (1,470)	100%/100% (1,470)	100%/100% (1,470)	100%/100% (1,470)
HOS	100%/0% (4,1185)	100%/0% (4,1363)	100%/0% (3,2596)	100%/0% (3,2596)	100%/0% (6,3264)	100%/0% (8,3424)	100%/0% (16,2622)	100%/0% (8,1220)	100%/0% (7,1117)	100%/0% (13,2736)

*Blue indicates Subjective-Direct, Yellow indicates Objective-Indirect, White indicates Objective-Direct, -- Not existent yet

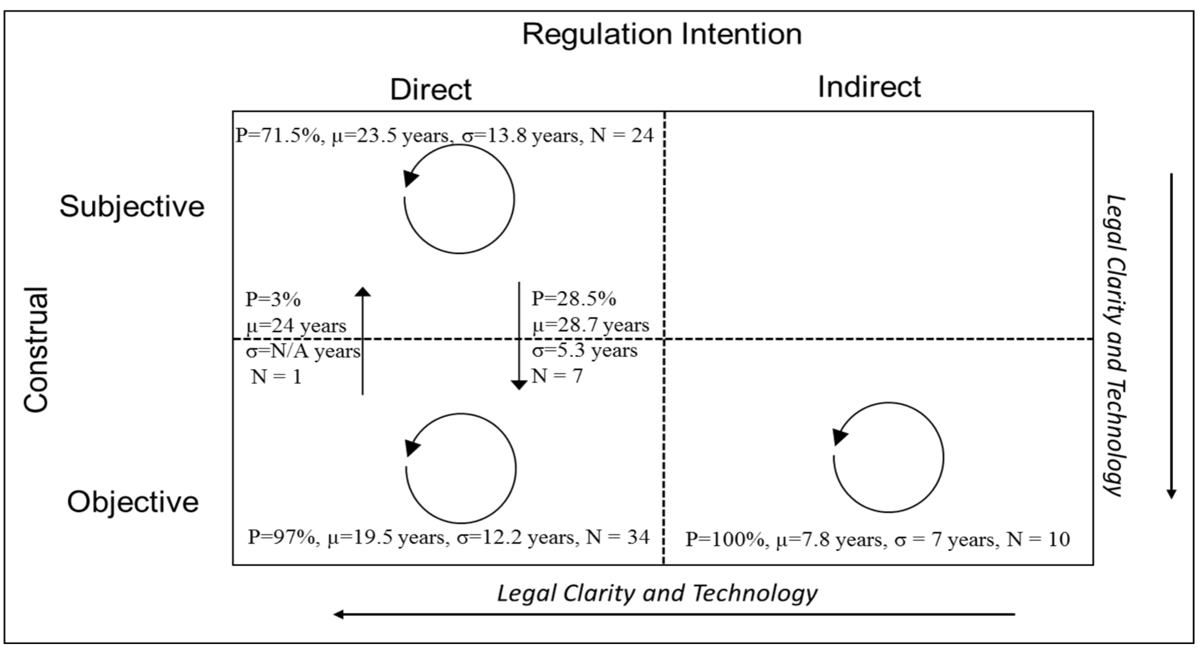


Figure 4: Type Movement

The Federal Register (FR) sometimes provided the rationale for the change in regulation. Oral hearings and written testimonies were also examined in the FRs to determine the impetus for the change in regulation *type.* Upon changing regulatory *type*, the majority of reasons for the change were due to three main factors: 1) legal clarity, 2) availability of new technology, 3) comprehensive regulatory reform (change in standards and or new aspects to regulate). These reasons for *type* change are depicted in Figure 4. Although entire regulations did not change from *type* indirect to direct, there were sections of the regulation that did change due to legal clarity and technology. For example, in 1988 a bill was passed to stipulate that blood alcohol content of drivers not exceed .004, which moved aspects of the overall regulation from indirect to directly measurement due to the ability to utilize technology (FHWA Docket No. MC-128 1988). Therefore, legal clarity and technology are possibly the catalysts for change in an indirect to a direct *type.*

Empirically testing to see if the *types* are different in the conceptual model is accomplished by statistically analyzing the *type* characteristics (time until regulation change, characters, and sections). The *types* (objective-direct OD, subjective-direct SD, and objective-indirect) were significantly different from one another (see Table 3) for characters and sections (p-value < .0001). Subjective-direct regulations were statistically different from both the objective-direct (p-value .017) and objective-indirect (p-value .003) regulation *types.* However, there was no statistically significant difference between objective-direct and objective-indirect (p-value of .16) regulation *types.*

Table 3 Typology Characteristic Comparison (Character count, Section Counts, Years until Substantial

	Objective Direct (OD)			Subjective Direct (SD)			Objective Indirect (OI)			Comparison
	μ	σ	n	μ	σ	n	μ	σ	n	(P-Value)
Character Count	1866.7	1235.6	553	637.5	623.7	439	2432.0	826.0	79	OI>OD>SD (<.0001)
Section Count	9.9	6.6	553	3.5	3.5	439	7.25	3.7	79	OD>OI>SD (<.0001)
Years Until Substantial Change	14.4	15.3	43	23.5	13.7	25	7.8	7.0	11	SD>OD (.017), SD>OI (.003)

Discussion and Conclusion

The conceptual typology model created provides the ability to further differentiate regulations. Although this study does not discuss the efficacy of these different *types* of regulations, it can be assumed that based on the changes in regulation *type* there are more preferred or effective *types* of regulation. If a change occurred, subjective-direct regulation *types* moved to objective-direct 28.5 percent of the time, and only moved back 3 percent of the time (due to a unique situation), leading to 7 of the 11 initially subjective-direct *type* ending as an objective-direct *type.* This implies that objective regulations seem to be preferred to subjective regulations.

One main observation of this research is that the Hours of Service (HOS) is the only regulation from the sample that began and ended as an indirect *type.* No regulations moved from direct to indirect or indirect to direct, but since the majority of regulations are classified as direct it would seem that this *type* of regulations is preferred. Since HOS is regulating a factor related to fatigue but not fatigue itself, it makes more sense why this regulation is continually changed. This regulation substantially changed on average every 7.09 years. This was significantly more frequent than subjective-direct (p value .003) *type*. In the event that a technology came out that could measure driver fatigue, HOS regulation may become direct. Until that time, it is very likely that more HOS regulatory reform will continue in an attempt to indirectly regulate fatigue. This sentiment was captured in the following ICC commissioner quote of 1937:

> We have no control over the manner in which a driver may spend his time off-duty, although some of his spare time activities may tire him as much as any work would do. We can only emphasize, by this comment, the responsibility which is the driver's own to assure himself of adequate rest and sleep, in the time available for this purpose, to ensure safety of his driving, and likewise the employer's responsibility to see that his drivers report for work in fit condition (ICC, 1937).

Another discussion point that this research finds is the duration a *type* of regulation remains the same. Subjective-direct regulations *types* (19.67 years) changed significantly less frequently than objective-direct *types* (13.67 years) and objective-indirect *types* (7.09 years) (see Table 3). This research found that for most regulations, an objective approach appears to be preferred over time. However, some subjective regulations did not change *types*. A possible explanation for this is a lack of availability of new technology. For example, the hazardous conditions regulation (392.14) remained completely subjective-direct from 1938 to 2016. This regulation did not change much from its original form in 1938:

Extreme caution in the operation of motor vehicles shall be exercised under hazardous conditions, such as snow, ice, sleet, fog, mist, rain, dust, smoke, or any other condition, which adversely affects visibility or traction, and speed shall be reduced accordingly.

It is possible to make this regulation objective but the technology is not readily available. For instance, airports use technology to provide very objective and detailed reports regarding the airport environment such as the runway surface condition (RSC) and the runway visual range (RVR). Attempting to do this on all roads would be prohibitively expensive and therefore, this regulation remains subjective. However, aspects of this regulation may begin to become more objective in the near future due to technologies like Light Detection and Ranging (LIDR), which may provide objective information about current visibility restrictions due to smoke, fog, rain or other particulates.

Another major finding of this research is the statistical difference among the size (characters, and sections) of the different *types* of regulation. Of the three *types* classified in this research, all were significantly different (p-value <.0001). Subjective regulations were the smallest, which could be explained by lack of regulation needed to describe intent rather than enforceable procedures. The objective-indirect *type* was substantially larger than either objective-direct or subjective-direct *types.* Since there are many indirect factors that contribute to the problem, indirect regulations may naturally grow in size to attempt to control these many factors.

The theory of disjointed incrementalism has been used to further explore the policy governing the trucking industry. This research analyzed regulations from the past 80 years to understand how and why regulations move or change. From this retrospective, longitudinal research, it seems that regulations change incrementally and disjointedly due to the limited knowledge, political feasibility and outside influences. For example, exemptions, especially when studied longitudinally, provide evidence to the disjointed nature of lawmaking. To illustrate this point, some of the HOS regulation exemptions occurred for agriculture drivers (1940), oilfield drivers (1963), or drivers in Alaska (1964). Regulations continually grow in size. Based on the proposed rules, regulations found in the federal register and Table 3, it appears that regulations grow incrementally based on political feasibility and expediency.

Given the new regulation typology proposed by this research, there is a plethora of future research needed to either further substantiate it or find its weaknesses in different fields. Additional research can be conducted on different characteristics of the *types* discussed in this research. Some of these include the efficacy of the regulation or rule to see which regulations tend to provide better results regarding their intended objective. Other characteristics such as cost could be explored in order to provide a better cost-benefit of different regulation *types*.

The implications of this research are far-reaching due to the practical typology created. Managers, legislators, and government agencies can benefit from understanding the different classifications while creating or modifying rules and regulations. Creating only subjective rules may most likely lead to less control and ambiguous policies, while creating objective regulations may lead to greater control and clearer policies. Indirect policies may lead to more changes over time and more complex regulations. In creating rules and regulation, it would appear that some initial subjectivity is needed to provide the intent and goal, while the majority of the regulation should seek to be objective to provide more legal clarity and to utilize emerging technologies.

III. Evaluating Hours-of-Service Impact on Truck Driving Capacity and Safety Implications: An Application of Perishable Inventory Theory

Abstract

Federal Motor Carrier Safety Administration (FMSCA) stipulates the Hours of Service (HOS) regulations in order to minimize or eliminate fatigued truck driving, a major cause of truck-related accidents. This research utilizes an Exhaustive Enumeration technique in order to find optimal discrete values for the various different HOS regulations. For example, this research found that drivers could accumulate 28.6 percent more average daily driving hours in 2012 than in 2014 due to the change in HOS regulations that occurred in 2013. Eleven HOS regulation changes have occurred since 2003. This ever-changing regulatory environment has many safety implications to the truck driving industry. Perishable inventory theory is introduced and used to provide the lens to understand how companies and truck drivers operate within this environment, providing a unique view on possible unintended consequences created by some of the recent HOS regulations.

Introduction

Historically, fatal accidents involving truck drivers have often resulted in heightened press, public outcry, and motor carrier regulation reform (Jensen & Dahl 2009). For example, in 2005 when a fatigued truck driver struck a high school bus, killing five band members and injuring many others, the result was increased scrutiny of truck driver time limits, also known as Hours of Service (HOS) (Plungis & Voreacos 2014).

More recently, in 2014, comedian Tracy Morgan was seriously injured and his friend, James McNair, was killed in an accident caused by a fatigued truck driver. An investigation revealed the truck driver was on duty for nearly 14 hours, the maximum allowed by HOS regulations. Additionally, the driver had been awake for more than 24 hours, allegedly rendering him unable to react appropriately (Margolin et al. 2014). This accident was widely publicized in the press, and the public demanded action (Margolin et al. 2014). Just prior to this accident, the True Safety Act was anticipated to easily pass in the House of Representatives, which would have redacted certain controversial HOS provisions. However, some legislators feared that redacting these provisions would have appeared as a relaxing of the regulations, and therefore, it was not pursued (Pyke 2014). Over time, as public interest subsided, the True Safety Act eventually passed. Although it is clear that the truck driver was fatigued, it is possible that certain HOS regulations are creating some accidents due to the additional stress on truck drivers that leads to fatigue (Min 2009b), and possibly more fatigue from changing driving times.

The passing of this act mainly concentrated on suspending two of the most controversial rules of the restart provision (The restart provision allows truck drivers to reset their duty time log back to 0, as long as certain stipulations are met). Two of the three restart provisions that were suspended detailed the number of restarts a truck driver could take (limit of 1 restart per 168 hours), and the coinciding time of the restart (must occur over two full consecutive 1 am to 5 am periods). These recent provisions were suspended until future research was conducted.

Due to the many recent HOS changes, questions arise concerning the stability and effectiveness of the HOS regulations, creating a need for further research and debate on the issues. Although fatigue has been linked to higher accident rates (Dinges 1995; Mackie & Miller 1978; Williamson & Friswell 2013; Summala & Mikkola 1994; Zhu & Srinivasan 2011), the effectiveness of HOS regulatory policy on reducing fatigue and making roads safer is still unclear (Arnold et al. 1997; Min 2009b). Prodigious research has been accomplished regarding accidents involving trucks due to fatigue (Morrow & Crum 2004; Abrams et al. 1997; Dingus et al. 2006); distracted driving (Olson et al. 2009; Hanowski et al. 2005); stress, health and narcotics (Taylor & Dorn 2006; Hartley & Hassani 1994; Crouch et al. 1993); scheduling (M. R. Crum & Morrow 2002; Min 2009b); and attitudes (Douglas & Swartz 2009). This dissertation research incorporates this previous research and builds upon it by using perishable inventory theory as the theoretical foundation to provide a more comprehensive examination of the efficacy of HOS governing the perishable product of truck drivers' time.

Truck drivers' time has two perishable aspects – deterioration and obsolescence. Truck drivers' abilities deteriorate with each passing hour, and they become less safe to navigate the roadways due to fatigue (Min 2009b). Truck drivers also become temporarily obsolete due to Hours of Service (HOS) regulations, even though they may be able to drive safely. This occurs because the regulations stipulate that the driver must stop driving at the end of the given restrictive period. In both scenarios (deterioration and obsolescence), a truck driver's time is perishable; as such, perishable inventory theory and some of its concepts (Nahmias 1974; Nahmias 1975; Nahmias & Pierskalla 1976; Nahmias 1982) are important to this research and can be used to better understand the impact of HOS on the trucking industry. Some of the essential tactics used in perishable inventory theory to maximize the utilization of perishable goods and services in this research are: 1) long-term plan, 2) flexibility, 3) first-in-first-out (FIFO) and last-in-last-out (LIFO), 4) capacity, 5) substitution and elimination, and 6) heterogeneity (Nahmias 1974; Nahmias 1982; Kishore et al. 2011; Fitzsimmons 1985; Siferd et al. 1992).

As previously stated, HOS regulations have been recently changing. These changes alter one or all of the previously mentioned perishable inventory tactics; and consequently, have different safety implications for truck drivers. For example, if truck drivers operated under the 1 restart per 168 hours restriction and the 1 am to 5 am provision, more capacity (a key perishable inventory tactic) may be achieved by driving during the day than at night even with significant congestion. Since research has associated higher accident rates with more congestion (Campbell 1995; Kononov et al. 2008), it is logical that the 1 restart per 168 hours restriction and the 1 am to 5 am provision, could have negative safety implications for truck drivers.

As another example utilizing a different tactic of perishable inventory theory—flexibility, suppose a truck driver can only operate 14 hours of duty per day, which is a rolling clock and starts upon the first duty (FMSCA 2015). If a truck driver wants to take a nap due to a moderate or severe impairment of the natural circadian rhythm (Grugle 2014), the 14-hour running restriction may disincentivize the truck driver to rest. This rigid regulation reduces the flexibility (Jensen & Dahl 2009) and could lead to increased fatigue and greater negative safety implications for some truck drivers.

In order to understand the implications of HOS on truck driver safety, this research investigates two aspects of the regulatory environment that can alter the tactics of perishable inventory theory—the frequency, and the magnitude of regulatory changes. This research is organized in four main sections: literature review, methodology, analysis, and conclusion. First, the literature review provides the background regarding HOS history and perishable inventory theory, creating the link of perishable inventory theory concepts to labor and its applications within perishable goods and services. Next, the paper will discuss the methodologies used followed by an analysis and discussion section providing additional insight on how the updated HOS regulations have changed truck drivers' ability to provide their perishable service. Lastly, this research will suggest future research in this field and conclude with managerial and regulatory implications.

Literature Review

The literature review is divided into two sections. The first introduces perishable inventory management and identifies some of the tactics mentioned in research related to perishability to frame the discussion on possible HOS safety implications on the trucking driving industry. The second section provides a background on HOS regulations.

Perishable Inventory

This research uses an approach advocated by Raafat (1991) which combines the perishable inventory theory literature (Nahmias 1982) and the deteriorating goods literature (Bakker et al. 2012). Both of these bodies of literature discuss tactics that can be used to deal primarily with tangible goods, whereas the Perishable Asset Revenue Model (PARM) and Yield Management literatures primarily discuss strategies for optimizing the use of services and labor (Weatherford & Bodily 1992; Kimes 1989). Even though these different bodies of literature tend to focus on either goods or services (which can be problematic since there are very few pure goods or pure services), the tactics used to reach end goals are often very similar. For instance, both goods and labor are critical aspects to the manufacturing process (Sengupta et al. 2006). Like inventory, a shortage of labor will produce less of a service or finished good while too much labor increases overhead and waste (Rogerson 1992; Aghazadeh 2003).

Goyal and Giri (2001) categorize inventory into two main categories: deterioration and obsolescence. Deterioration denotes a natural degradation and ongoing loss of value or quality over time. Deterioration occurs in many items such as blood, drugs, and food. Using the correct tactics ensures that these items have greater utility (Nahmias 1975). Other items, such as clothes and computers experience a different problem — obsolescence (Siriruk 2012). Obsolescence is different from deterioration, because it refers to an instantaneous loss of value without a corresponding loss of quality. Obsolescence is caused by many reasons, such as changes in technology or in customer preferences and because of regulations.

Perishable inventory theory submits that goods deteriorate linearly or exponentially over time, and goods become perishable mainly due to deterioration (Nahmias 1975). Similar to perishable goods, labor also experiences both types of perishability: deterioration and obsolescence. For example, a truck driver experiences perishable deterioration through loss of skills, mainly due to fatigue (Grugle 2014) because subsequent driving hours are associated with lower performance or utility and lead to an increased risk of an accident (Short & Murray 2014). On the other hand, regulatory policy can lead to obsolescence due to drivers reaching the maximum amount of driving or duty hours in a given period. Unlike the permanent obsolescence of milk, which the U.S. Federal Drug Administration (FDA) prohibits being sold after the expiration date (although it may still be safe to drink), a truck driver's obsolescence is temporary and can be reset through rest. The U.S. Federal Motor Carrier Safety Administration (FMSCA) prohibits driving after the regulated hours (even though the truck driver may still be safe to drive). Hence, truck drivers are affected similarly to perishable inventory: they experience deterioration through natural fatigue, and they are subject to obsolescence due to regulation.

Properly following certain tactics protects against the aspects of deterioration and obsolescence of perishable products. These tactics (as shown in Figure 5) are capacity, substitution and/or elimination, strategic planning, flexibility, FIFO or LIFO, and heterogeneity.

These tactics were identified from the various bodies of perishability-related literature and are discussed in more detail in the following sections.

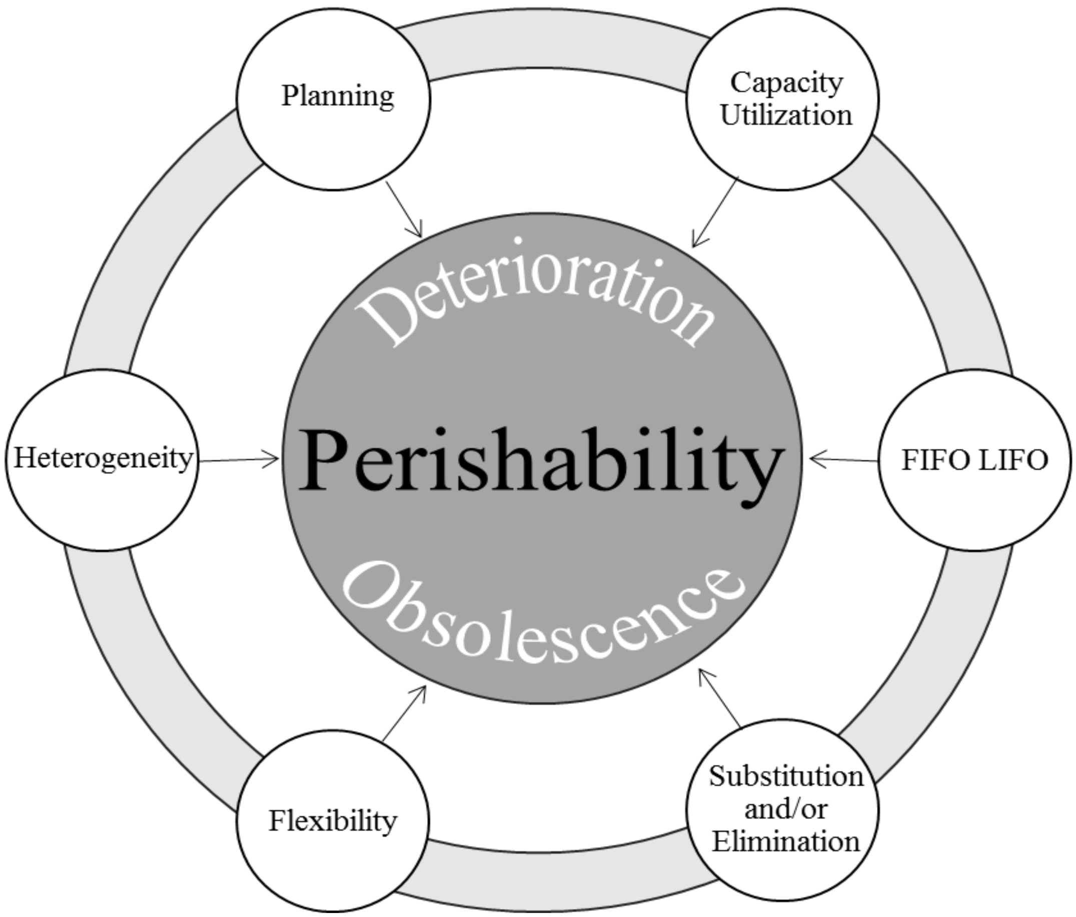


Figure 5 Commonly Used Tactics for Dealing with the Aspects of Perishable Inventory Theory, Yield Management, and Perishable Asset Revenue Model (PARM)

Although perishable goods and labor have similarities concerning deterioration and obsolescence, they have one primary difference—labor hours cannot be accumulated or stocked. They are produced and consumed simultaneously, otherwise known as *simultaneity* (Fitzsimmons et al. 2013). Consequently, unused labor becomes instantly obsolete as time passes. As a result of this type of obsolescence, two other bodies of literature regarding perishability are utilized to bridge this gap: Yield Management (Kimes 1989) and the Perishable Asset Revenue Model (PARM) (Weatherford & Bodily 1992). Unbooked airline seats, empty hotel rooms, unrented cars, unfilled trucks, unutilized doctors' and nurses' time are all examples of perishable services classified under both yield management and PARM (Weatherford & Bodily 1992; Kimes 1989). These fields help provide more guidance concerning the tactics used when obsolescence rapidly occurs. For example, an empty airline seat becomes obsolete the moment the plane takes off, as does the empty space in a trailer when a truck leaves a docking station. Similarly, unused labor is instantly lost if it is not productive. One of the main tactics explored, to deal with rapid obsolescence, is service capacity utilization.

Service capacity utilization is a metric that helps ensure that the service is rendered and does not become unfulfilled or obsolete (Weatherford & Bodily 1992). Both physical capacity and labor capacity are inputs into service capacity utilization (Siferd et al. 1992). Within the trucking industry, physical capacity is the infrastructure needed to conduct operations (truck, trailers, loading docks, etc.) and labor capacity is the operator of the equipment (truck driver). Optimizing profits occurs from correctly pairing the right amount of physical capacity and labor capacity (Siferd et al. 1992). HOS regulations dictate the duration of driving or duty time truck drivers can operate, and when these regulations change so does labor capacity and the optimal service capacity utilization. Thus, service capacity utilization may be an important tactic for understanding the impact of HOS on truck drivers' perishable time.

Fitzsimmons (1985) discusses the concepts of service capacity utilization that are appropriate for service professions such physicians; noting the permanent loss to the service provider when physicians are idle. He also discussed how to increase the utilization of physicians' time through elimination or substitution. Elimination involves completely removing non-value-added aspects from physicians' workloads, whereas substitution involves shifting activities to lower-level staff within the medical organization. Shifting activities (substitution) such as filling out paperwork or prescreening to lower-level staff directly increases the utilization of the physicians' skill set (Jo Bitner et al. 1997; Fitzsimmons 1985). Furthermore, the more valuable or time-restricted the perishable service is, the more elimination of non-value-added activities and substitutions should occur. As an example of elimination, GPS provides better routes and aids in finding rest stops, which decreases navigation time and eliminates non-value-added time for drivers. Substitution, for instance, can be accomplished when fleet managers provide schedules to drivers, expedite loading/unloading, and manage maintenance times – ensuring minimal driver downtime. Suitably, the tactics of substitution and elimination may be critical for understanding the impact of HOS on the perishable time of truck drivers.

Having a plan is an important part of being able to carry out the tactics of elimination or substitution. Amorim et al. (2012) advocate the importance of a longer-term plan versus reactively dealing with the current problems of perishable goods. Perishable items can falsely necessitate action. Because the perishable items lose value and ultimately become a liability, focusing solely on the present can lead to greater losses through the replication of the same problems in future time periods (Amorim et al., 2012). Planning often results in better scheduling. Siferd et al. (1992) emphasized the importance of scheduling strategies to managers in service capacity planning. Truck companies must optimize profits by balancing the number of drivers and tractors needed to fulfill demand. When HOS changes, so do the workable hours for drivers thus, necessitating a change in the number of truck drivers in order to sustain the same service level (Holcomb et al. 2014; Min 2009b). A look at planning-related investments made by trucking companies may enable a better perspective of HOS regulation impact on the truck driving industry.

A good plan needs to allow flexibility to account for unknowns (Kishore et al. 2011) especially with regards to perishable goods (Roy, Kar, & Maiti, 2010). While planning truck drivers' perishable time, managers should consider providing flexibility to their drivers to account for breaks, construction and congestion delays, longer than expected unload or upload times, and breakdown of equipment; otherwise, a decrease in overall service level is more likely (M. R. Crum & Morrow 2002; Adams-Guppy & Guppy 2003). HOS regulations limit the flexibility of drivers, which has sometimes led to decreased safety (Jensen & Dahl 2009). Flexibility, correspondingly, is perhaps an important tactic for improving the overall service level of truck drivers and for understanding the safety implications of HOS regulations on truck drivers.

First- in-first out (FIFO) and last-in-first out (LIFO) are two different strategies employed in perishable inventory theory (Nahmias 1982). Using the oldest units first, (FIFO) minimizes the expected obsolescence, but increases the average age of the product, while conversely, using newer units first (LIFO) decreases the average age of the products being delivered, while often leading to more obsolescence (Nahmias 1982). Let us use two drivers as an example. Driver 1 has already accumulated driving hours, while Driver 2 has not driven in the current time period. As a long route becomes available, a LIFO approach would use Driver 2 because Driver 1 does not have enough HOS time remaining to complete the route. For a shorter route, a FIFO approach could utilize the remaining HOS of Driver 1, ensuring non-obsolescence, thus saving Driver 2 for future routes. Therefore, the tactics of FIFO and LIFO can be used in realizing greater utility of truck drivers.

When dealing with perishable goods, managers need to be aware that not all of the goods deteriorate at the same rate or become obsolete at the same time. This is the concept of heterogeneity. Heterogeneous products that have not expired are not of equal utility or value (Nahmias 1982). Truck drivers should be considered heterogeneous because they do not have the same capability to manage their fatigue; thus they deteriorate at different rates. Obesity, age, and overall health are some of the factors that increase driver fatigue (McCartt et al. 2000; FMSCA 2015). For example, Stoohs et al. (1994) showed that obese truck drivers were twice as likely to have an accident as non-obese drivers. Research has also found that younger drivers (Summala & Mikkola 1994; Horne & Burley 2010), and older drivers (Wang & McDonald 2004; Mitler et al. 1997; McGwin Jr & Brown 1999) are associated with deteriorated skills due to fatigue. In essence, truck drivers' time cards or Electronic on Board Recorders (EOBR) may be the same, but they may offer different performance levels of service and safety. Correspondingly, heterogeneity can be used to understand the possible HOS implications on truck drivers' perishable time.

Perishable goods are categorized as one of the most difficult inventory problems due to their limited life, loss of revenue due to deterioration and obsolescence, cost of disposal, and increased likelihood of stock out (Kishore et al. 2011). In order to manage these challenges, the following tactics were extracted from the perishable research literature and are used in this research to investigate the implications of HOS on the truck driving industry: capacity utilization, substitution and/or elimination, planning, flexibility, FIFO and LIFO, and heterogeneity.

Hours of Service Background

Federal Motor Safety Carrier Association (FMSCA) establishes HOS regulations for truck drivers. These regulations stipulate the maximum duty and driving hours of truck drivers. Moreover, HOS rules limit both daily and weekly duty and driving hours of truck drivers. Government agencies have stated that regulation in the trucking industry is important because of the increased potential of an accident that occurs as truck drivers work additional hours (FMSCA 2015). Soccolich et al., (Soccolich et al. 2013) discussed the increased rate of safety incident occurrences based on accumulating driving time (see Figure 6). This figure shows that truck drivers become more of a safety liability as they reach higher driving hours. Previous research has also filled gaps regarding the source of truck driver accidents. Most of this research has measured the effects of singular restrictions and accidents with respect to fatigue, some examples of effects include: multi-day driving patterns (Kaneko & Jovanis 1992), starting fatigue level (M. R. Crum & Morrow 2002), driving hours per day (Hanowski et al. 2009; Soccolich et al. 2013), driving time of day (Blower & Campbell 1998), breaks (Chen & Xie 2014a), sleeper-berths (Hertz 1988), truck miles (Lyman & Braver 2003; Joshua & Garber 1990; Jovanis & Chang 1986), and truck driver health (Anderson et al. 2012). These types of research efforts have been influential in changes that have been made to HOS regulations in the past. The following section provides a historical perspective of some of these changes.

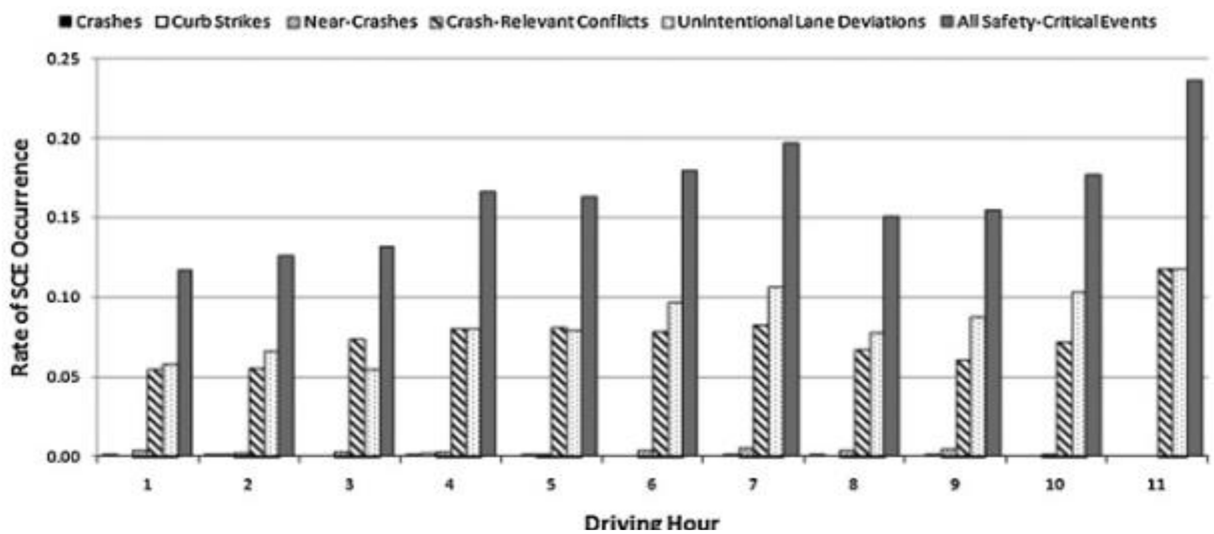


Figure 6 Incident rate and driving hour (Soccolich et al., 2013)

History of Hours of Service (HOS)

The Motor Carrier Act of 1935 authorized the Interstate Commerce Commission to regulate commercial motor vehicles. In 1938, HOS was enacted with six main provisions (see Table 4) ("Federal Register, Volume 65 Issue 85", 2000). Shortly after the first HOS release, there were two provisions and two redactions in 1939. The next change occurred in 1962, removing the duty cycle provision. In 2003, three changes were made and regulators added two new rules, a sleeper berth provision, and a restart provision. In 2005, there was one change regarding the minimum number of hours authorized in a sleeper berth. In 2013, there were three new laws added: one stipulated a mandatory break within the first 8 hours of duty, and two

Table 4 History of HOS

Year Changed	1938	1939	1962	2003	2005	2013	2014
Driving Hours	**12**	**10**	10	**11**	11	11	11
On-Duty Hours	**15**	**N/A**	N/A	**14**	14	14	14
Max Daily Work	**12**	**N/A**	N/A	N/A	N/A	N/A	N/A
Off-Duty Hours	**9**	**8**	8	**10**	10	10	10
Duty Cycle	**24**	24	**N/A**	N/A	N/A	N/A	N/A
60 Hour (7-day)	**60**	60	60	60	60	60	60
70 Hour (8-day)	**70**	70	70	70	70	70	70
Break						**≥8**	≥8
Restart				**≥34**	≥34	≥34	≥34
Number of Restarts						**1 Per 168 Hrs**	**N/A**
1 am to 5 am						**≥2**	**N/A**
Sleeper Berths Split Sleep				**≥2 hrs**	**≥8 hrs**	≥8 hrs	≥8 hrs
Changes	**7**	**4**	**1**	**5**	**1**	**3**	**2**

restricted the use of the restart provision. In 2014, these two restart provisions were removed pending reevaluation (FMSCA 2015). The number of HOS changes is reflected graphically in Figure 7. Out of the total 23 changes, additions, or redactions; nearly half (11) of them have occurred since 2003, indicating that the past decade has been particularly disruptive and uncertain for the trucking industry. The following section provides specific details concerning HOS regulations that have been relevant since 2013.

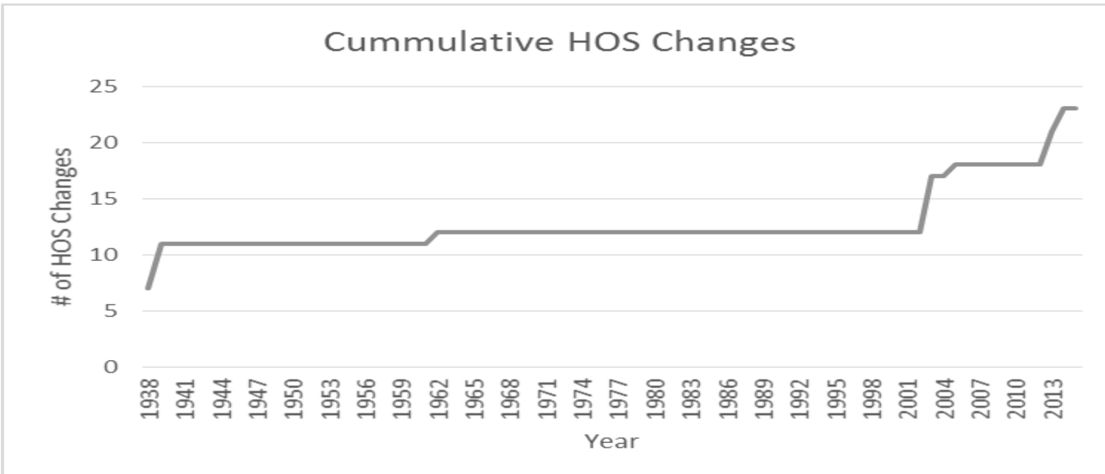


Figure 7 Number of HOS Changes

Recent Hours of Service Regulations

Since 2013, the relevant daily HOS regulations mandated that truck drivers cannot drive more than 11 hours per day, cannot be on duty for more than 14 hours per day and must have a 30-minute break within the first 8 hours of duty (FMSCA 2015). The weekly HOS regulations further restrict the daily HOS regulations. Truck drivers can either utilize a maximum of 70 duty hours within 8-days (if the company he/she is driving for operates 7-days a week) or 60 duty hours within 7-days (if the company he/she is driving for operates 6 or fewer days per week). One other regulation within HOS is the restart provision. The restart provision allows the truck driver to rest for a certain period, thereby resetting all duty and driving hours back to zero. The July 1, 2013 HOS update limited restart uses to 1 restart per 168 hours restriction or 1 per week. It also stipulated that the restart must last at least 34 hours and must coincide with two full 1 am to 5 am periods (FMSCA 2015). The December 14, 2014 HOS update removed these restart limitations, except for the 34-hour provision.

The goal of the July 1, 2013 HOS update was to decrease extensive working hours, thereby reducing fatigue-related crashes and long-term health problems for truck drivers (FMSCA 2015). The Federal Motor Safety Carrier Association (FMSCA) predicted that this rule would decrease acute and chronic fatigue while only cutting work hours by 15 percent (2015). In 2013 there were 342,000 crashes, 95,000 injuries, and 3,964 fatalities involving trucks (NHTSA 2015). The regulatory policy proposed was anticipated to prevent 1,400 crashes (a reduction of .41 percent), 560 injuries (a reduction of .59 percent), and 19 deaths (a reduction of .48 percent) involving trucks per year (FMSCA 2015). The 2013 updated HOS rules have come under scrutiny due to unintended consequences (Ferro 2014), higher associated costs than estimated (Short 2013), and shortcomings regarding methodologies utilized to evaluate HOS changes (Goel 2014; Brewster & Short 2014). This dissertation research provides additional insight into this ongoing discussion.

Method

This research builds upon previous research by viewing the impact of HOS regulations on truck drivers through the lens of perishable inventory theory. HOS regulations restrict the hours that truck drivers can operate, as such, this research primarily analyzes the capacity differences of these provisions. In order to understand the capacity differences in the various HOS regulations, MATLAB v8.4 simulation was first utilized for the analysis of capacity differences due to its coding flexibility in discrete modeling (Grewal & Andrews 2014). This approach provided a general solution for most situations; however, due to the difficult interactions of constraints (weekly, daily, restarts, and breaks), the simulation missed some sub-optimal solutions that were discovered using a different technique—Exhaustive Enumeration. Exhaustive Enumeration is a simple (yet very time-consuming) optimization approach that evaluates all the solutions for different combinations of discrete variables in order to identify the region of feasible solutions. Utilizing a similar approach to Itti and Gokak (2013), the Exhaustive Enumeration (EE) method provided optimal discrete values for all possible HOS regulatory combinations. Utilizing the values generated by the EE method, all optimum discrete points (average daily driving hours) were identified and graphed on a continuous scale.

Since the majority of truck drivers are paid per mile (Short 2013), and driving hours is a good substitute for miles driven (Braver et al. 1999), this research used average daily driving hours. Optimizing average daily driving hours enables comparisons, with respect to capacity, of the different interactive effect of HOS regulations (daily, weekly, and restart provisions). Most previous studies use a *daily view* to look at the effects of long duty hours on a given day (Williamson et al. 1996; Hanowski et al. 2009; Soccolich et al. 2013; Chen & Xie 2014b). Some previous studies use a *weekly view* to look at the compounding effects of multi-day operations on fatigue (Beilock 1995; Mackie & Miller 1978; Kaneko & Jovanis 1992). Using this new approach of average daily hours allows the analysis to consider *both a daily view and weekly view*, but expresses the results in a way that is easy for truck drivers to understand their true capacity given all constraints caused by the regulations.

Since truck drivers can increase average daily driving hours based on changing start and end times, certain classifications are needed in order to enumerate average daily driving hours. In the absence of HOS regulation, there are several reasons truck drivers would alter their schedules: personal preferences, traffic congestion, disparate speed limits that occur at night, and pickup/delivery windows. HOS regulations have created incentives for truck drivers to change their schedules to maximize their capacity in two ways. First, since the 24-hour duty cycle (first introduced in 1938 and removed in 1962) no longer exists, truck drivers can currently change their *daily schedules*. Second, truck drivers have an incentive to alter their *weekly schedules* at the beginning or end of the week to optimize the restart time based upon the 1 am to 5 am provision. Because of these different options created by the HOS regulations, this analysis utilizes an approach similar to that of Murray and Short (2015) and considers three different classifications types of drivers: 1) truck drivers that have *no schedule changes*, 2) truck drivers that have *weekly schedule changes* (at the start or end of each weekly time period), and 3) truck drivers that have *daily schedule changes*. The relevant HOS provisions used in this analysis (and their corresponding lines on HOS logbooks) are discussed in the following paragraphs.

The *daily* HOS regulations restrict the amount of driving and duty time and require breaks and rest time (constraints shown below). Driving time is restricted to 11 hours per period. Duty time is restricted to 14 hours per period, starts at the beginning of a shift, and accumulates continuously until being reset by 10 consecutive off-duty hours. A 30-minute break is required in any given 8-hour duty period. For purposes of the analysis, the *daily restrictions* are expressed mathematically as follows:

$$\begin{aligned}
&\textit{Driving Time} \leq \textit{11 hours}\\
&\textit{Duty Time} \leq \textit{14 Hours}\\
&\textit{Consecutive Hours Off Duty} \geq \textit{10 Hours}\\
&\textit{Break} \geq \textit{30 Minutes (if duty time is} \geq \textit{8 consecutive hours)}
\end{aligned}$$

Unlike *daily* HOS regulations, *weekly* HOS regulations only restrict duty hours. The 70 duty hours over 8 days or 60 duty hours over 7 days provisions prescribe the maximum amount of hours that can be attained during that timeframe without a restart being used. A truck driver is under the 70-hour provision if the company he/she is driving for operates 7 days per week, and is under the 60-hour provision if the company operates 6 or fewer days per week. While any break time counts against the 14-hour duty clock mentioned above, it does not count towards weekly duty time provisions. Only duty or driving time count towards these 8-day or 7-day hours; meaning that break times during the day count only against the 14-hour clock. These *weekly restrictions* lead to the following additional mathematical expressions:

$$\textit{Duty Time} \leq 60 \textit{ hours (for 7 day period)}$$
$$\textit{Duty Time} \leq 70 \textit{ hours (for 8 day period)}$$

The final set of mathematical expressions that are necessary for the analysis involve restarts. The restart provision before July 1, 2013 allowed for an unlimited number of restarts and required a consecutive 34-hour break. From July 1, 2013 to December 16, 2014 the restart provision still required a consecutive 34-hour break; but also mandated that the break period include two consecutive 1 am to 5 am periods and also limited the number of restarts to 1 restart per 168 hours restriction. In this analysis, when the 1 am to 5 am provision is used it is in combination with the 1 restart per 168 hours restriction. The *restart-related restrictions* are stated mathematically as:

$$\textit{Restart} \geq 34 \textit{ hours}$$
$$\textit{Restart Number} < 1 \textit{ per 168-hours}$$
$$\textit{Restart} = 2 \textit{ consecutive nights (1 am to 5 am)}$$

The Exhaustive Enumeration (EE) method was based on maximizing truck-driver driving time. This was accomplished using a layered approach by first optimizing daily driving hours, followed by accounting for the 70-hour (8-day) or 60-Hour (7-day) constraints, and then by considering the different restart constraints (Unlimited, 1 restart per 168 hours restriction, and 1 restart per 168 hours restriction with the 1 am to 5 am provision (see Figure 8). The discrete values used in EE to optimize driver capacity were based on the smallest time restriction – the mandatory 30 minute break. Thus, 48 different start times were analyzed starting at 00:00 and ending at 23:30. This study examines and compares the maximum average daily driving hours that a truck driver can operate under the different restrictions and helps illustrate the implications of the perishable inventory theory tactics.

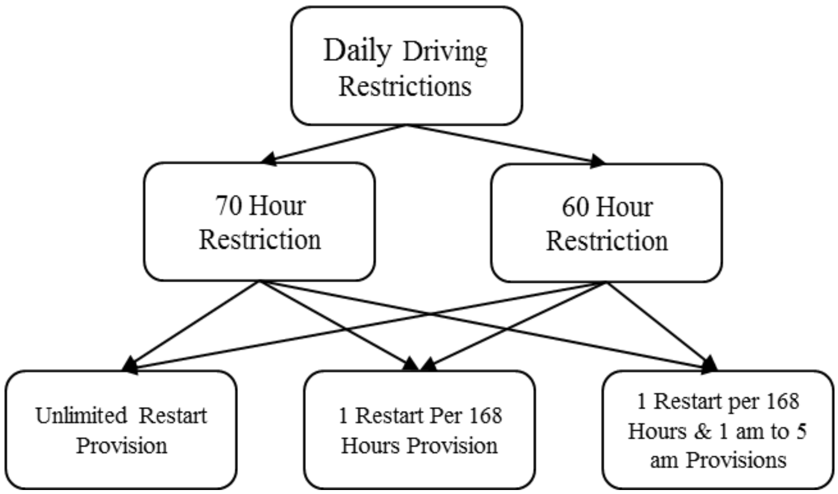


Figure 8 Layered Aspects of HOS

In addition to the above considerations, the analysis also accounts for the effects of congestion on average daily driving hours. Congestion and the 1 am to 5 am provision create preferred driving times. In order to generalize the effects of congestion, this research utilized the buffer index (BI). BI was used in the 2011 Congested Corridors Report (Eisele et al. 2011) and ensures 95 percent on time rate by adding additional “buffer time” to the schedule or route based on statistical data gathered from 328 different traffic corridors across the country. The 328 different traffic corridors Buffer Indexes are averaged in order to provide the best sample for approximating congestion across America. Since traffic congestion varies by location, a sensitivity analysis from zero to 260 percent BI is applied.

Analysis

The analysis calculates average daily driving hours under several different scenarios to determine capacity utilization. Since truck drivers predominantly operate under the 70-hour provision, most of the analysis uses the 70-hour constraint[1]. The first section analyzes truck drivers that have *no schedule changes* except those immediately following a change to a given HOS regulation. Truck drivers that have *weekly schedule changes* (at the start or end of each weekly time period) are addressed in the second section, followed by a section addressing truck drivers that have *daily schedule changes*. The final section provides the mathematical rationale for the unintended consequences of increased congestion due to the 1 am to 5 am provision.

No Change in Truck Driver Schedule

Some truck drivers operate on regular, stable, and consistent schedules that do not fluctuate from day-to-day or from week-to-week (*no schedule changes*). When HOS regulations are changed, these drivers may alter their schedules to adapt to the new provisions, but will then

[1] The average daily driving hours are lower for the 60-hour restriction and there are similar patterns in the results except for one aspect – 168 hours equals 7 days, thus the 60-hour (7-day) restriction falls within the same time period as the 1 restart per 168 hours, eliminating any restart benefit.

maintain the revised schedule going forward. Although a truck driver can drive fewer than 11 hours per day, Figure 9 shows the maximum average daily driving hours that can be achieved under various HOS regulations and highlights the points of divergence, which are created by these restrictions. All restrictions equate to the same average daily driving hours up to 9.25 hours of duty per day (.5 hours for a break and 8.75 hours of driving). The 8-day (70-hour) rule begins to diverge the amount of average daily driving hours that can be achieved and limits the average daily driving to 8.75 hours (70 hours ÷ 8 days = 8.75) until a restart occurs. The next point of divergence occurs at 10.8 duty hours above which restarts provide greater average daily driving hours than the 70-hour restriction.

The final divergence occurs at 12.5 duty hours and separates the unlimited restart provision from the 1 restart per 168 hours restriction and 1 am to 5 am provision. Under the unlimited restart provision, a truck driver can begin a restart period at any time. Under the 1 restart per 168 hours restriction a driver can still begin a restart at any time, but taking a restart at any point prior to 134 duty hours will translate into a restart period being longer than the minimum required 34 hours, thus leading to lower average daily driving hours.

Table 2 shows that drivers cannot actually drive 11 hours on average per day (as a simple look at the HOS regulations might suggest). Instead, 9.43 hours is the maximum average daily driving hours that can be achieved under any of the HOS regulations, assuming no schedule changes. For purposes of calculating the maximum and average percent differences, only the points to the right of the first divergence are included. The data points inside the shaded box are excluded because they are the same for all of the different provisions and restrictions. The 70-hour restriction is the most limiting in terms of average daily driving hours. Under the daily restrictions, a driver can see a 54.6 percent increase in average daily driving hours over what can be achieved under the 70-hour restriction.

The analysis shows that restarts can be very beneficial in terms of improving average daily driving hours. Table 5 shows that unlimited restart provision can improve daily driving averages significantly. When compared to the 70-hour provision, the unlimited restart provision can increase daily driving averages by up to 28.6 percent. However, there are substantial differences between the various restart provisions. The unlimited restart provision yields a 12.5 percent increase in average daily driving hours over the 1 restart per 168 hours restriction.

Table 5 Percent Difference between Restrictions and/or Provisions Assuming No Changes to a Truck Driver's Schedule

Comparison of Restrictions and/or Provisions	Max %	Average
70-Hour Restriction Vs. 1 Restart Per 168 Hour Provision	14.6%	8.0%
70-Hour Restriction Vs. Unlimited Restart Provision	28.6%	11.7%
70-Hour Restriction Vs. Daily Restrictions	54.3%	28.7%
1 Restart Per 168 Hour Provision Vs. Unlimited Restart Provision	12.5%	3.3%
1 Restart Per 168 Hour Provision Vs. Daily Restrictions	35.0%	18.6%
Unlimited Restart Provision Vs. Daily Restrictions	20.0%	14.7%

As Figure 9 shows, improving the efficiency ratio (driving time ÷ duty time) greatly improves the number of average daily driving hours, which in turn affects capacity. While the lines in this figure illustrate the maximum average daily driving hours that can be legally driven under the various restrictions and provisions, drivers can certainly achieve lower average daily driving hours that may be dictated by customer requirements. After 12.17 daily duty hours (11.67 duty hours counted against the weekly 70-hour limit because of the 30 minute break), the truck driver begins to lose driving capacity. This occurs because driving is limited to 11 hours per day, and adding more duty hours limits potential duty time on future days. Specifically, for every minute of duty over 12.17 hours, a minute of driving is lost during one of the days left before the next restart period. This demonstrates what can be accomplished by eliminating or substituting non-value added duty time (one of the tactics used to deal with perishability) thus ensuring maximum driving time and increasing the efficiency ratio.

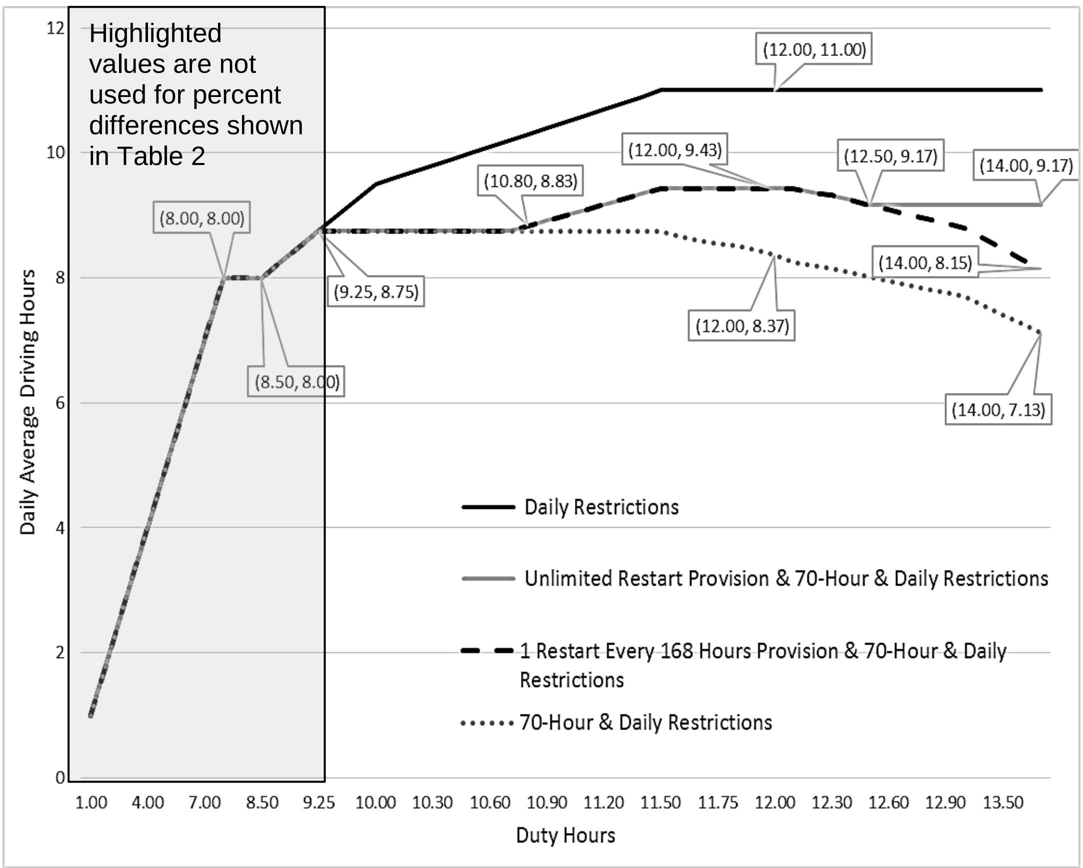


Figure 9 Maximum Average Daily Driving Hours under Various HOS regulations for Drivers Following a Consistent Schedule

Weekly Change in Truck Driver Schedule

Weekly schedule change refers to altering a truck driver's end time on the day before the beginning of the restart and/or the start time on the day after the completion of the restart. These two changes (which are a consequence of the 1 am to 5 am restart provision) are discussed in greater detail in the following paragraphs.

Changing the end time on the day before the restart may enable a truck driver to decrease the duration of the restart, thus, increase average daily driving hours. For instance, a truck driver who operates 14-duty hours per day and desires to avoid a restart that is longer than the required 34 hours should begin operating between 5 am and 11 am, thus ending before 1 am (see Figure 10 Timeline A). This occurs because the 1 am to 5 am provision requires two complete and consecutive periods. If a truck driver works past 1 am, the driver will not be able to count any portion of that 1 am to 5 am time period as part of their restart. For example, if a truck driver begins at noon and stops at 2:00 am, the required restart duration would be 51 hours rather than 34 hours that it could have been if the driver had stopped working at 1:00 am (see Figure 10 Timeline C). Increased restart hour duration can also occur if the truck driver ends too early, because additional hours of waiting are needed until the 5 am provision is reached. For instance, if a truck driver begins his/her 14-hour duty day at 20:00 (8 pm) and ends at 10:00 the next day, the restart duration would be 43 hours (see Figure 10 Timeline B). These two examples illustrate that the restart duration can change based upon the end time prior to the beginning of the restart period.

After completing a restart, a truck driver can either choose to wait to start driving until his/her normal start time, or choose to begin driving immediately following the restart (at 5 am) and then maintain on that revised start time for the remainder of that duty week. The choice they make, based on their preferences, can lead to what we have labeled a *preference penalty*, which, if incurred, decreases average daily driving hours. For example, if a truck driver begins at 20:00 and ends at 10:00 (a 14-hour duty day), the driver's restart duration is 43 hours (due to 2 complete and consecutive 1 am to 5 am periods) and then an additional 15 hours (from 05:00 to 20:00) is needed to begin at the normal start time (see Figure 10 Timeline D). A truck driver could actually begin driving immediately after the restart is complete at 5 am, thus, eliminating the addition 15 hours of preferred waiting time. Figure 11 Timeline E provides a similar example of a preference penalty and also demonstrates that the sum of the restart period and the preference penalty durations ranges from 34 hours to 58 hours under a 14-hour duty day scenario. As the restart period duration increases, the preference penalty duration decreases by the same amount.

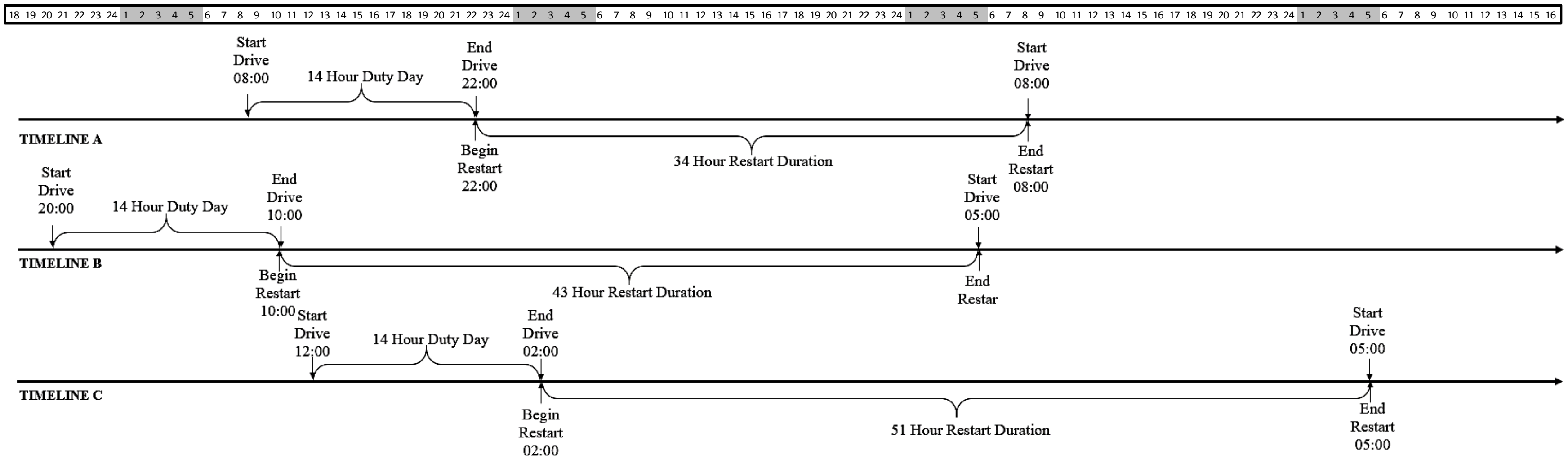


Figure 10 Restart Duration Examples

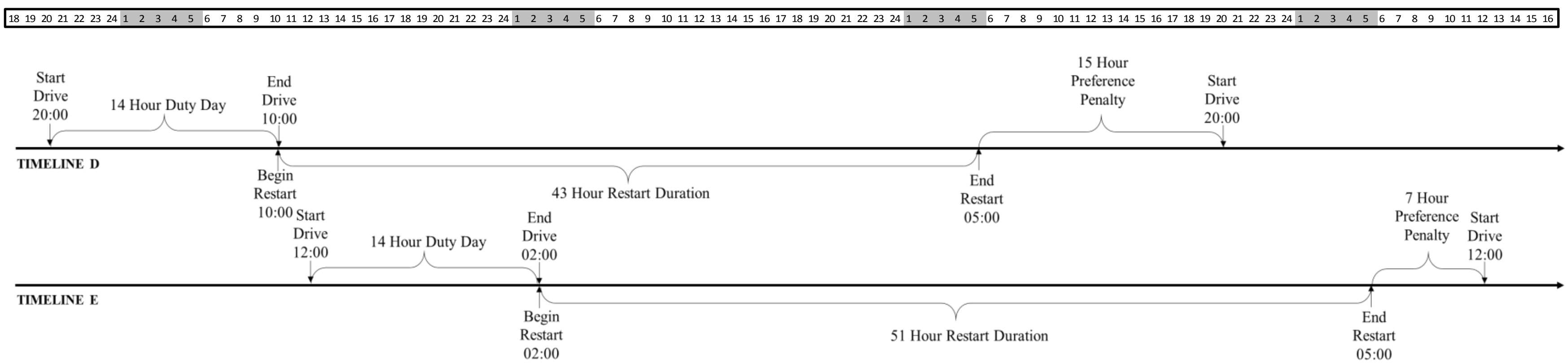


Figure 11 Preference Penalty Examples

Various equations were generated using the Exhaustive Enumeration (EE) method to better understand the relationship between the restart period and the preference penalty durations. In order to maximize the average daily driving hours, a truck driver needs to minimize the restart period and preference penalty durations. To do this, the driver must start within a specific time window. This specific window and other relevant variables are defined mathematically as follows:

Equations Group 1: Hours of Service Variables

dutyPeriodHours = truck driver daily duty duration
startTime = time truck driver starts duty
startHours = the difference between 0 am and startTime
restartHours = duration of restart period
preferencePenaltyHours = length of delay due to driver preferred start time
lostHours = restartHours + preferencePenaltyHours

windowStartTime = 5 am
windowHours = 20 hours – dutyPeriodHours
windowEndTime = 5 am + windowHours

The mathematical definitions above can be utilized to calculate restart period, preference penalty, and total hours as follows:

Equations Group 2: Truck Driver Restart Hours

If windowEndTime ≥ startTime, then restartHours = 34 hours

If windowEndTime < startTime, then restartHours = (57 hours + windowHours) - startHours

Equations Group 3: Truck Driver Preference Penalty Hours

If startTime ≥ 5 and If windowEndTime ≥ startTime, then preferencePenaltyHours = 14 hours – dutyPeriodHours

If startTime ≥ 5 and If windowEndTime < startTime, then preferencePenaltyHours = startHours – 5 hours

If startTime < 5 am, then preferencePenaltyHours = 19 hours + startHours

Truck Driver Restart Hours & Truck Driver Preference Penalty:

Equations Group 4: Truck Driver Restart and Preference Penalty Hours

If windowHours + 5 hours ≥ startHours, then totalHours = 48 hours – dutyPeriodHours

If windowHours + 5 hours < startHours, then totalHours = 52 hours + windowHours

These equations were utilized to construct Figure 12, which illustrates the total restart hours that correspond with various start and end times for truck drivers working 8, 11, or 14 duty hours per day. In this figure, the bottom region represents the *windowHours* for the truck driver. If a truck driver begins his/her duty day outside the *windowStartTime and windowEndTime* (illustrated in Figure 12), the *totalHours* can increase by 71 percent (from 34 to 58 hours).

Further analysis illustrates the relationship between *totalHours* and the average daily driving hours (see Figure 13 and Table 6). Since the truck driver can legally choose to incur a *preference penalty*, three different levels were created for average daily driving hours: low, medium and high. Low indicates a truck driver having the longest restart period and *preference penalty durations* possible and therefore achieving the lowest possible average daily driving hours (operating outside the *windowStartTime* and *windowEndTime*). Medium indicates the average *totalHours* for all of the 48 enumerated start and corresponding end times. High indicates a truck driver operating within the *windowStartTime* and *windowEndTime*, thereby achieving the highest average daily driving hours under the 1 am to 5 am restart provision.

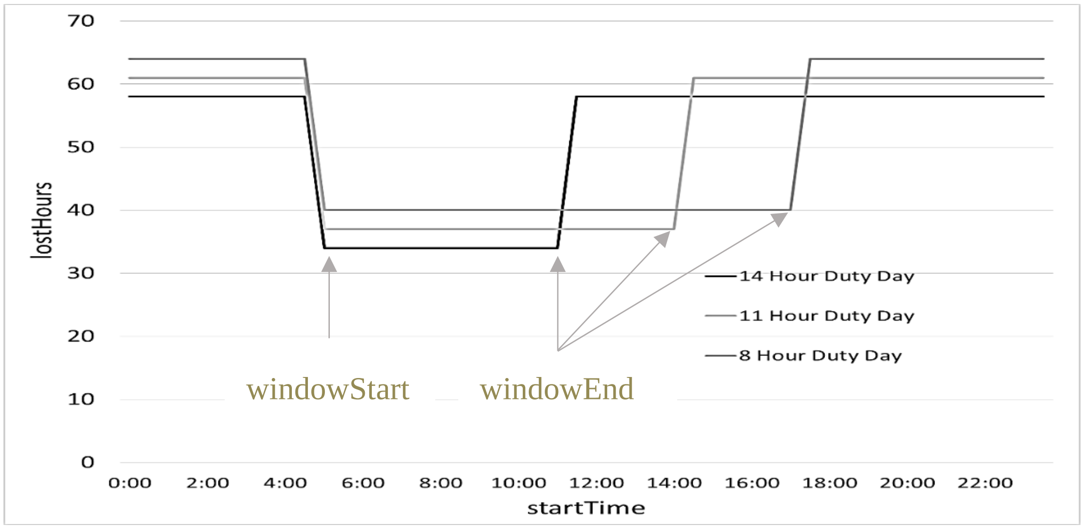


Figure 12 1 am to 5 am Provision Start Times

As shown in the Figure 13, utilizing a restart (under the 1 restart per 168 hours restriction and 1 am to 5 am provision) is not beneficial until the driver operates more than 10.7 hours on average within the first 6 days. At 11.5 hours the maximum amount of average daily driving hours are achieved for all three categories 9.43 (high), 8.63 (medium), and 8.25 (low).

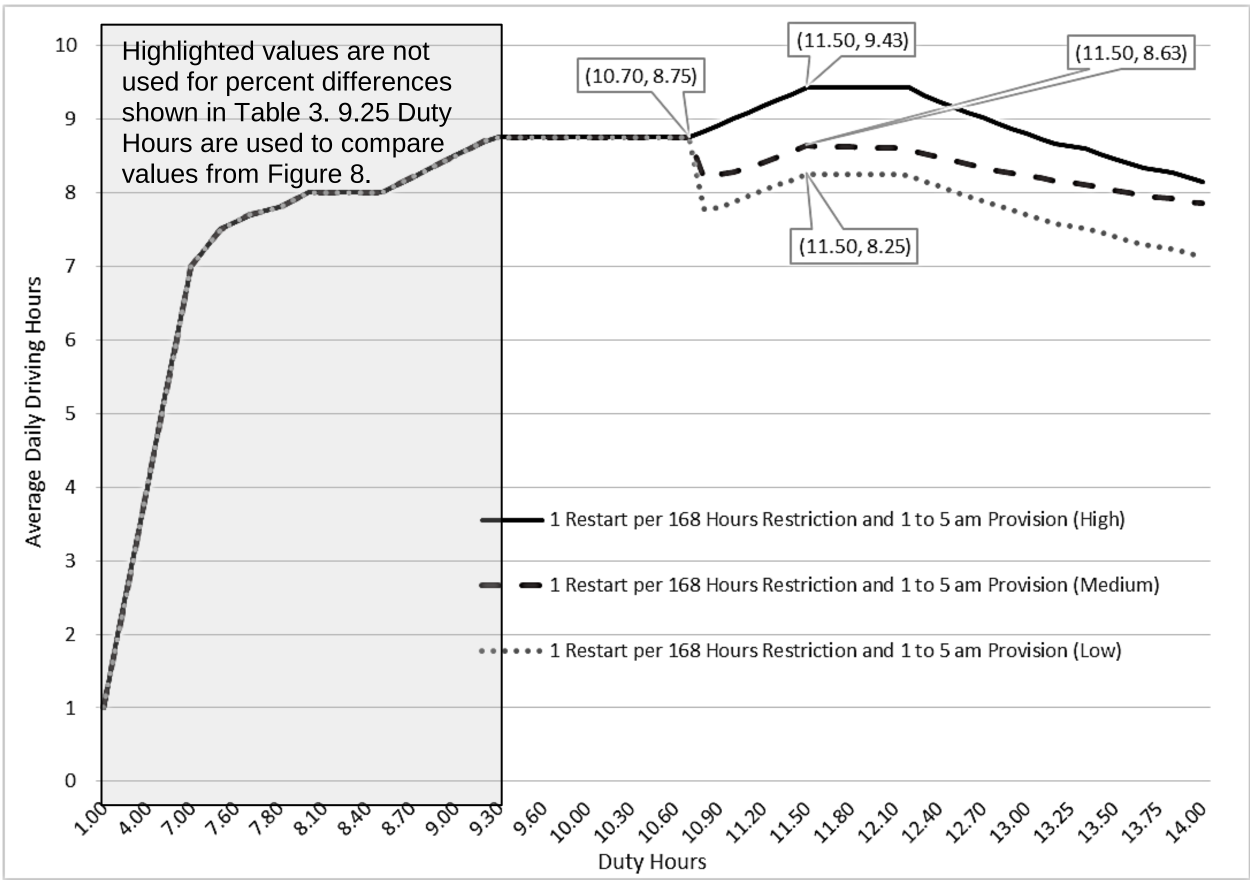


Figure 13 1 am to 5 am Provision and Average Daily Driving Hours

Table 6 directly compares the maximum average daily driving hours that can be achieved under the various HOS regulations. A truck driver under the 1 restart per 168 hour restriction and 1 am to 5 am provision *low* (see Table 6) drives a maximum of 10.2 percent less than a 1 restart per 168 hour restriction and 1 am to 5 am provision *medium*, and a maximum of 14.6 percent less than 1 restart per 168 hour restriction and 1 am to 5 am provision *high*.

Furthermore, a truck driver in the 1 restart per 168 hours restriction and 1 am to 5 am provision *low* will drive 12.5 percent (max) and -1.5 percent (average) fewer hours than if he/she operated under the 70-hour provision only, and 28.6 percent (max) fewer hours than using the unlimited restart provision. This indicates that there are numerous schedules that will never benefit from using a restart under the 1 restart per 168 hours restriction and 1 am to 5 am provision; restricting the truck drivers to the 70-hour restriction and indicating a large impact to trucking capacity for these schedules. Conversely, for the 1 restart per 168 hour restriction and 1 am to 5 am provision *medium* there is an increase of 10.2 percent over the 70-hour restriction, indicating that the restart is indeed beneficial.

The different restart provisions and associated average daily driving hours illustrate large capacity changes, which provide equally large incentives for truck drivers to alter their weekly schedules to increase capacity through the perishability tactics of proper planning, flexibility, and heterogeneity. The next section analyzes *daily changes* to a truck driver's schedule that can

Table 6 Comparison of Restrictions and/or Provisions Assuming No and/or Moderate Truck Driver Schedule

Comparison of Restrictions and/or Provisions	Max % Difference	Average % Difference
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. 70-Hour Restriction	12.5%	1.9%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium)	10.2%	4.2%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. 1 Restart Per 168 Hour Restriction 1 am to 5 am (High)	14.6%	9.8%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. Unlimited Restart Provision	28.6%	12.2%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. Daily Restrictions	54.3%	29.8%
70-Hour Restriction Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium)	10.2%	2.4%
70-Hour Restriction Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (High)	14.6%	7.8%
70-Hour Restriction Vs. Unlimited Restart Provision	28.6%	10.2%
70-Hour Restriction Vs. Daily Restrictions	54.3%	27.4%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium) Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (High)	9.8%	5.3%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium) Vs. Unlimited Restart Provision	16.7%	7.5%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium) Vs. Daily Restrictions	40.0%	24.2%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (High) Vs. Unlimited Restart Provision	12.5%	2.1%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (High) Vs. Daily Restrictions	35.0%	17.8%
Unlimited Restart Provision Vs. Daily Restrictions	20.0%	15.3%

increase capacity even more.

Note: *Daily Driving* indicates the 14-hour duty restriction, 30-minute break requirement, and 11-hour driving restriction. *70-Hour* indicates the layering of the daily driving restrictions and the 70-hour (8-day) restriction. *Unlimited* indicates the layering of the daily driving restrictions, the

70-hour (8-day) restriction, and the unlimited restart provision. *168 Low*, *168 Medium*, and *168 High* indicates the layering of the daily driving restrictions, 70-hour (8-day) restriction, and the 1 restart per 168 hours restriction with the 1 am to 5 am provision.

Daily Change in a Truck Driver Schedule

Although it is unlikely that a truck driver would change his/her schedule *daily* for a lengthy time period (multiple weeks or months), it is likely that under the right incentives a truck driver would change his/her schedule *daily* for a shorter period (multiple days or a week). Change to *daily* driving start times can increase average daily driving hours dramatically because it capitalizes on the fact that there is no 24-hour cycle mandate. For example, a truck driver can legally be on duty for 12 hours, accomplishing 11 hours of driving, sleep for 10 hours and then begin again after 22 hours have passed. This will allow a truck driver to begin duty again 2 hours prior to their previous start time and enable the truck driver to accumulate more average daily driving hours. By having *daily schedule changes*, it is possible to drive an average of 10.35 hours per day (a 9.8 percent increase over not making *daily schedule changes*) under the unlimited restart provision – the highest possible driving hours that can be legally achieved (see Figure 9 and Figure 14). Although less than the hours accumulated under the unlimited restart provision, the 1 restart per 168 hours restriction also increases the average daily driving hours to 10 hours from 9.43 hours. No increase in average daily driving hours is achieved under only the 70-hour restriction.

As Table 7 illustrates, the unlimited restart provision offers 32.2 percent higher average daily driving hours than the 70-hour (8-day) restriction; 20.2 percent higher average daily driving hours than the 1 restart per 168 hour restriction (low), and up to a 15.7 percent higher average daily driving hours than the 1 restart per 168 hour restriction (medium and high).

Although capacity is increased, there are dramatic changes to the daily schedule, which impact a truck driver's circadian rhythm. At the highest average daily driving hours,

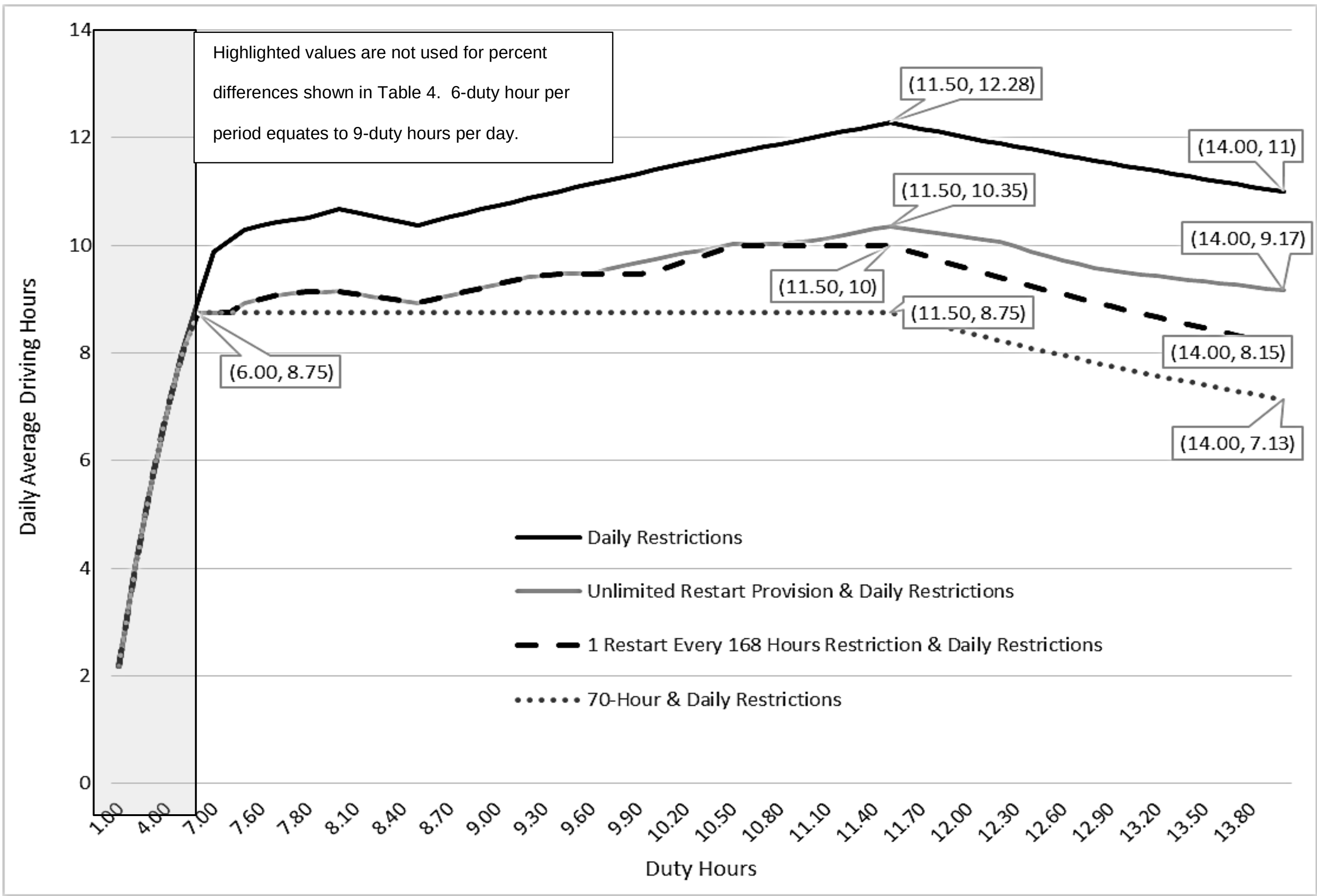


Figure 14 Daily Change in Truck Driver Schedule

11.5 hours duty and 11 hours of driving, a truck driver would begin to drive 2.5 hours earlier than his/her previous start time. After 6 cycles (66 hours of driving) a truck driver would have swapped his/her scheduled start time by 12.5 hours. A truck driver could also switch their cycle by a lesser amount, but it would still have a cumulative impact on his/her circadian rhythm.

Table 7 Daily Changes in Truck Driver Schedule

Comparison of Restrictions and/or Provisions	Max % Difference	Average % Difference
70-Hour Restriction Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low)	10.0%	3.4%
70-Hour Restriction Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium)	14.3%	8.7%
70-Hour Restriction Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (High)	14.3%	10.9%
70-Hour Restriction Vs. Unlimited Restart Provision	32.2%	16.3%
70-Hour Restriction Vs. Daily Restrictions	54.3%	37.1%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium)	6.7%	5.2%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (High)	10.4%	7.4%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. Unlimited Restart Provision	20.2%	12.3%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Low) Vs. Daily Restrictions	40.2%	32.3%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium) Vs. 1 Restart Per 168 Hour Restriction and 1 am to 5 am (High)	3.8%	2.1%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium) Vs. Unlimited Restart Provision	15.7%	6.8%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (Medium) Vs. Daily Restrictions	35.0%	25.8%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (High) Vs. Unlimited Restart Provision	15.7%	4.7%
1 Restart Per 168 Hour Restriction and 1 am to 5 am (High) Vs. Daily Restrictions	35.0%	23.4%
Unlimited Restart Provision Vs. Daily Restrictions	21.0%	17.8%

Comparison of Daily Schedule and No Schedule Changes

As already mentioned, daily schedule changes correspond to increased average daily driving hours. The magnitude of the differences between four scenarios representing *no schedule changes* and *daily schedule changes* are illustrated in Figure 15. At 10.5 hours of duty, a *daily schedule-changing* driver achieves 14.3 percent more (10 versus 8.75) hours of average daily driving under both the unlimited restart provision and 1 per 168 restart restriction compared to the unlimited restart provision for a driver with *no schedule changes*. Figure 11 also reveals that a *daily schedule-changing* driver operating under the 1 restart per 168 hour restriction will achieve more daily driving hours than the unlimited restart provision under *no schedule changes* for less than 12.2 duty hours. Thus, there is a significant increase in capacity through *daily schedule changes*, especially when compared to *no schedule changes*. A truck driver operating under *no schedule changes*, the 1 restart per 168 hour restriction, and 1 am to 5 am provision (low) experiences a 29 percent (max) decrease in capacity at 10.9 duty hours when compared to the unlimited restart provision and the 1 restart per 168 hours restriction and 1 to 5 am provision under *daily schedule* changes.

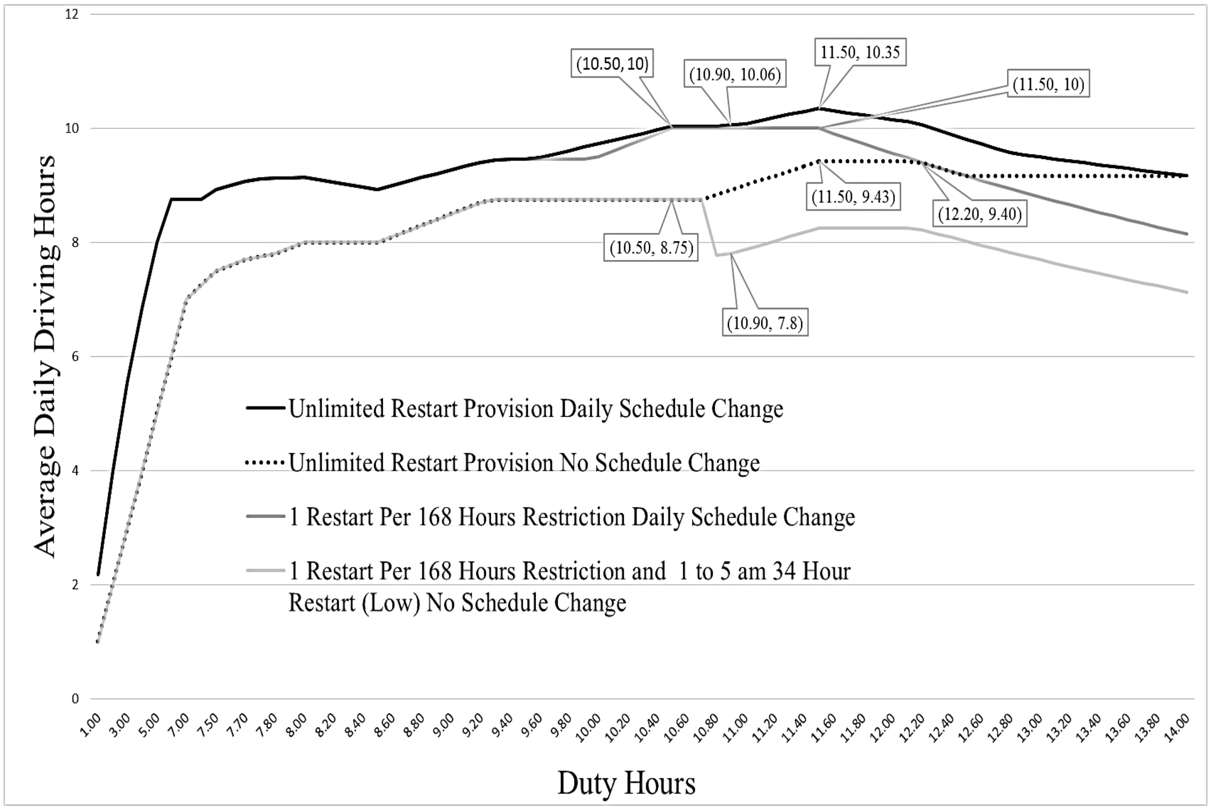


Figure 15 Daily Schedule Changes Vs. No Schedule Changes

This section reveals large incentives for truck drivers to increase their efficiency and reduce the cycle period duration in order to capture higher average daily driving hours. However, these incentives come with daily schedule changes, potential fatigue, and higher chance of an accident based on the heterogeneity capabilities (perishable concept) of the truck driver.

Congestion

The last section of the analysis details the implications of the 1 am to 5 am provision and one of its unintended consequences—increased congestion due to an increased incentive to drive during daylight hours (Short 2013; Ferro 2014). The analysis above has demonstrated that average daily driving hours can be increased when a truck driver operates within the optimal time frame (which for a 14-hour duty day, involves starting to drive between 5 am and 11 am). The more drivers who choose to operate within this optimal time frame, the more congestion is created, leading to decreased driving efficiency in terms of the distance that can be traveled during a given time period. This section analyzes the tradeoffs between driving during the optimal time frame (and facing increased congestion levels, thus reducing the overall miles driven) or driving outside the optimal time frame (and facing the consequences of increased restart duration and preference penalty hours which decrease average daily driving hours and thus the overall miles driven).

Congestion is the result of many factors: economic trends, weather, accidents, work zones, disparate speeds, and road capacity (Short and Murray, 2014). It is important to note that a truck increases congestion more than a car because of the increased size, decreased maneuverability, increased driving spacing, lower driving speed, and decreased acceleration capability (Kaisy, Jung, and Rakha, 2007). Research has shown that, in non-congested traffic, trucks are equivalent to 1.5 cars on a level freeway, 2.5 on a rolling freeway, and 4.5 on a mountainous freeway (HCM, 2000). Recent research has shown that these values are low when considering the effects of congestion, or stop-and-go traffic. For example, Kaisy et al. (2001) found that trucks account for 2.5 cars on a level freeway during congested hours; a 66 percent increase from a non-congested level freeway.

The 2011 Congested Corridors Report (CCR) establishes two different main congested periods, 6 to 10 am and 3 to 7 pm. During these congested periods, traffic speeds are reduced. Since the majority of truck drivers are paid per mile, their hourly driving is not as efficient in congestion. The CCR provides a buffer index (BI) (ranging from 10 to 260 percent) that can be used for planning purposes to ensure an on-time arrival rate of 95 percent when driving in congested traffic (see Figure 16 and the following equation).

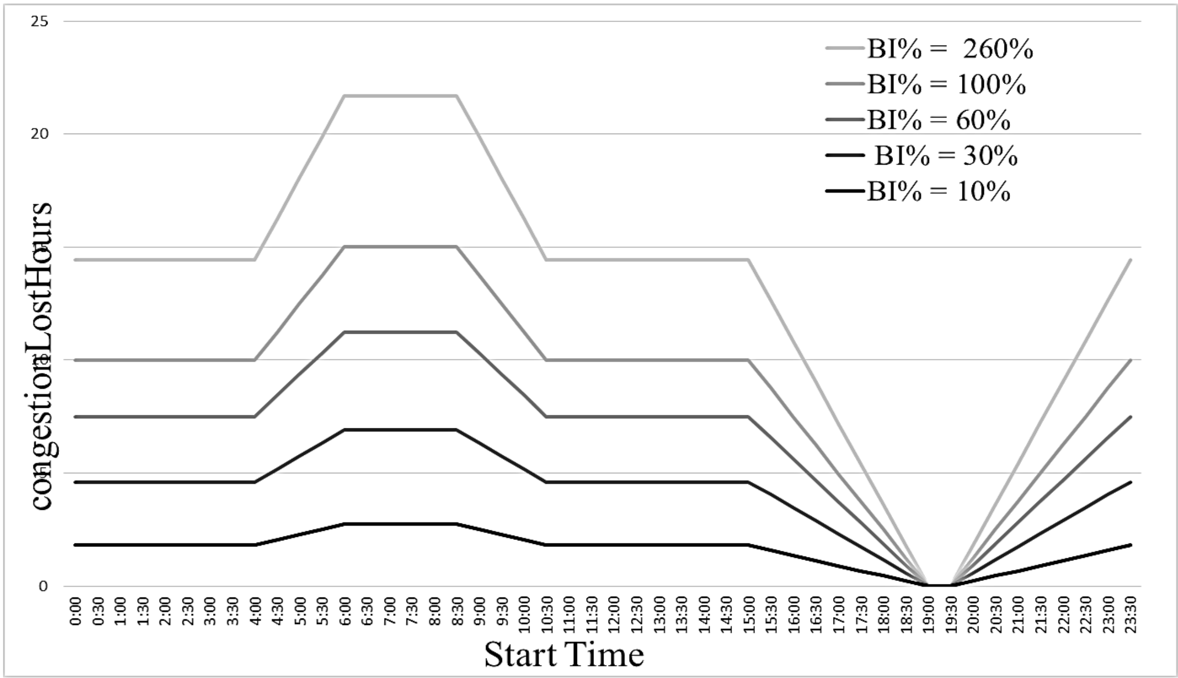


Figure 16 Congestion Lost Hours (Five 11-Hour days)

Equation 5: Congestion and Hours of Service Penalty Hours

totalLostHours = restartHours + preferencePenaltyHours + congestionLostHours

If a truck driver starts driving at 6 am and drives for 11 hours he/she drives during two main congestion periods (6 am to 10 am and 3 pm to 5 pm) for a total of 6 hours or 55 percent (6/11) of the time. Utilizing a BI of 100 percent, what would normally take 3 hours now incurs 3 *congestionLostHours* (for a total of 6 hours) due to the congestion. Therefore, after driving 5 days, this schedule produces 15 lost hours. However, starting at 7 pm (19:00) this schedule produces zero lost hours after 5 days because no congestion periods are encountered.

Figure 17 illustrates the rationale for truck drivers to ultimately switch to daytime schedules in order to minimize *totalLostHours*. Even a start time of 6 am with a BI of 260 percent has approximately four fewer *totalLostHours* than starting at 7 pm. Increasing congestion during the day, however, has many safety, economic, and environmental implications.

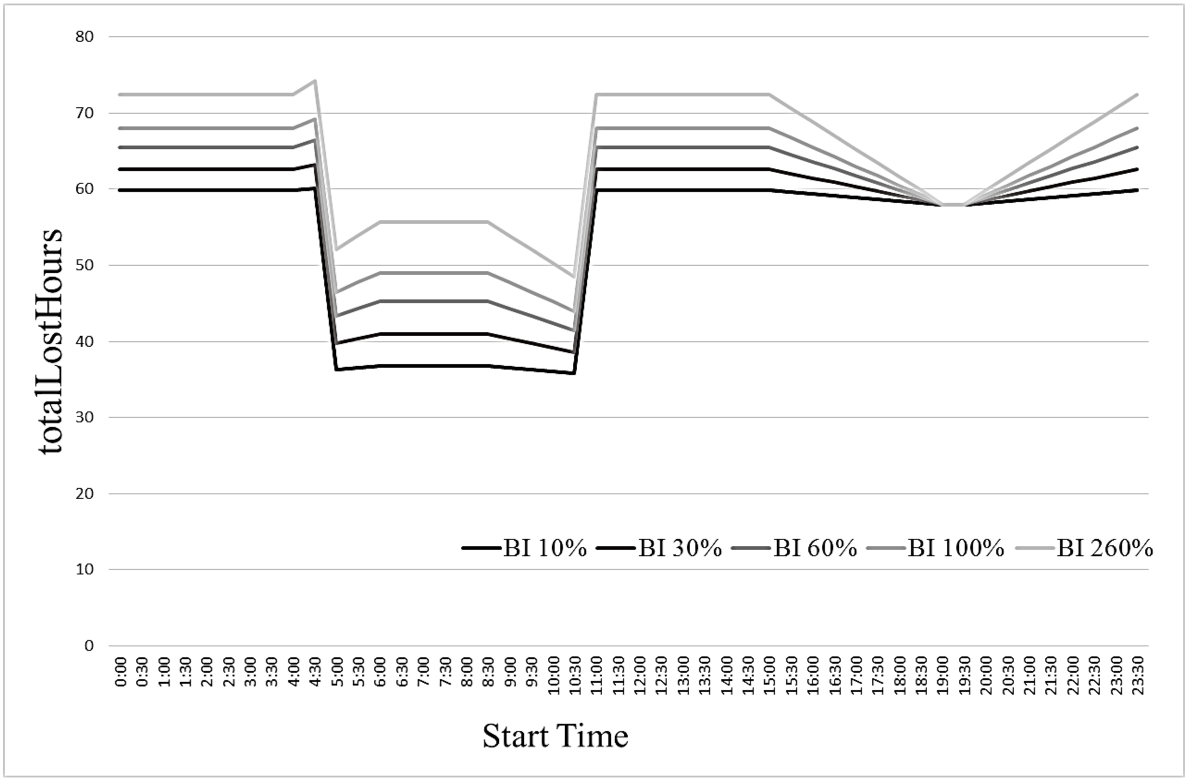


Figure 17 Congestion and 1 am to 5 am provision

Discussion

This section ties the analytical results above to the tactics from perishable inventory theory (capacity utilization, flexibility, substitution and/or elimination, FIFO and LIFO, and long-term plan) and discusses implications for truck drivers.

Capacity Utilization

Capacity utilization was measured by finding the maximum average daily driving hours under the different restrictions and provisions. The different restrictions and provisions along with the schedules of truck drivers (no, weekly, and daily schedule changes) were shown to have significant differences in capacity (see Table 6 and Table 7, and Figure 9, Figure 12, Figure 14 Figure 15).

Limiting how much a truck driver can drive has many ripple effects on the truck driving industry. When hours are changed for truck drivers, the balance between the number of tractors and drivers, distribution nodes, and support personnel change. For example, the 1 restart per 168 hours and 1 am to 5 am provision was found to significantly decrease the amount of driving by up to 28.6 percent (see Table 6). Since drivers could not operate as many hours, and companies desired to maintain the same service level, additional tractors, trailers and drivers were needed (Short 2013). Unfortunately, 80.1 percent of respondents from that study still indicated loss of productivity, even with the additional equipment and personnel. The addition of new equipment and hiring of new drivers have subsequent safety implications that are discussed more under the flexibility tactic.

Capacity is not only based upon the hours of driving but how efficient that driving is with respect to miles traveled. Congestion can restrict driving capacity further decreasing the miles driven by truck drivers than driving during non-congested periods. This research has shown that under the 1 am to 5 am provision, truck drivers can paradoxically achieve the least amount of total lost driving hours (and thereby increase the total miles driven) by operating during the congested daytime periods. By removing the 1 am to 5 am provision and operating under an unlimited restart provision, drivers would be able to drive more during uncongested time periods and thereby achieve even more miles. Research has shown that traffic flow was the single most important factor (more than circadian rhythm) in determining accident rate (Dingus et al. 2006). Moreover, higher disparity of speed differences between vehicle types has also been shown to increase accident rates, due to the acceleration and deceleration differences between large and small vehicles in congestion (Neeley & Richardson 2009). Basically, as congestion increases, the rate of accidents also increases (Kononov et al. 2008). Campbell (1995) suggested providing incentives for truck drivers to operate outside the congested periods in order to ameliorate the effect of increased congestion. However, FMSCA's 1 am to 5 am provision, resulted in the opposite by providing drivers an incentive to drive more during congested periods, which only adds to the congestion levels and possible related safety consequences (Commerce Appropriations Act, 2014).

Unfortunately, there are more negative impacts that result from the 1 am to 5 am provision such as increased CO_2 emissions. Operating a vehicle at lower average speeds because of more braking, accelerating, and idle time not only causes more wear on the equipment and subsequent higher disposal rates, but it also has a large environmental impact due to increased CO_2 emissions (Campbell 1995; Golias 2015; Figliozzi 2011).

Flexibility

HOS regulations are intended to restrict the hours that truck drivers can work or drive, thus, limiting their flexibility in several ways. Three of which will be discussed here. First, the analysis above has shown that the continuously accumulating 14-hour duty day restriction limits the choices that drivers can make (such as whether or not to take a nap) which can limit their capacity and consequently their ability to earn money. Evidence has shown that naps result in a lower accident rate and improved work performance (Macchi et al. 2002; Philip et al. 2006). Without the pressure created by the continuously accumulating duty hour restriction, drivers are free to nap when they are fatigued and drive when they feel rested. The continuously accumulating aspect of the restriction, creates a negative incentive for drivers to nap. Every minute a driver spends preparing for or taking a nap is a minute of their duty day that is lost and the rest of the week's schedule can be severely influenced due to the continuously accumulating duty hour restriction and the 10-hour break following the 14-hour limit. For example, a driver who takes a rest for 2 hours may no longer reach the desired location within the 14-hour window, which causes a delay of greater than 10 hours due to the mandatory 10-hour break. This decision to nap, therefore, can also influence the rest of the week's schedule through the loss or modification of future loads. As shown in this example, the continuously accumulating 14-hour duty restriction can provide large disincentives for truck drivers to take a nap or rest during their duty day. In fact, the majority of drivers who fall asleep reported that they were aware of their fatigue but continued to drive (Abrams et al. 1997). Furthermore, if the continuously accumulating aspect of the daily duty limit was removed, some truck drivers could avoid high congestion periods (6 to 10 am and 3 to 7 pm) by taking naps. This would not only reduce congestion, but increase truck driver's capacity due to a decrease in the total hours (see totalLossHours in Figure 17).

Second, the weekly provisions, including the 1 restart per 168 hours restriction and 1 am to 5 am provision (low) has been shown (see Table 6) in this analysis to decrease capacity by 28.6 percent (max) when compared to the unlimited restart provision and 14.6 percent (max) when compared to the 1 restart per 168 hour restriction and 1 am to 5 am provision (high). This decrease in capacity was the result of the increased restart duration and preference penalty hours from not starting a truck driver's day between 5 am and 11 am for a 14-hour duty day. Thus, this restriction and provision decreases the flexibility of times that truck drivers can maintain a certain capacity or service level. Furthermore, under the 1 am to 5 am provision, this research illustrated that truck drivers achieve higher driving efficiency by operating during daytime hours even with a congestion BI of 260% or 3.6 times slower than normal traffic.

The analysis above demonstrates *why* the OOIDA Foundation (2011) and Short (2014) found that a majority of drivers (approximately 79 percent) claimed that they lost flexibility in managing their schedule with their workload because of this restriction and provision; leading to driving during peak congested times as well as increased stress and fatigue levels. This dissertation analysis furthers this previous research by providing the economic rationale for these previous findings. For truck drivers who start between 5 am and 11 am (for a 14-hour duty day), a restart can lead to an increase in average daily driving hours (see Figure 9, Figure 13Figure 14). Whereas for truck drivers starting outside of the 5 am to 11 am period (for 14-hour duty day) the 1 restart per 168 hour restriction and 1 am to 5 am provision is not beneficial, which leads drivers to not use restarts unless a preference penalty is utilized: however, not using the preference penalty has ramifications on circadian rhythm. Furthermore, truck drivers operating during any time period of the day, under the 60-hour (7-day) restriction, do not benefit from a 1 restart per 168 hour restriction. Thus, almost all of HOS regulations restrict the number of driving or duty hours within a given period, but the 1 am to 5 am provision restricts the time of day (when) at which driving and duty should occur through monetary incentives.

Third, flexibility is also critical for businesses to optimally manage their workforce and equipment in order to meet required service levels. This research revealed that 23 total HOS regulations changes have occurred since 1938, and approximately half of them (11) occurred since 2003 (see Figure 7 and Table 4). These 11 changes were also significant with respect to the amount of average daily driving hours that can be achieved (see Table 4, Table 5, Table 6, and Table 7). This analysis demonstrates that the truck driving industry is in an uncertain and highly fluctuating regulatory environment. Research has found that companies who increase flexibility, through adaptation of schedules in uncertain regulatory environments, tend to succeed (Alexander 1991; Engau & Hoffmann 2011). Companies have achieved flexibility by making the workforce less permanent (Rugman & Verbeke 1998). Hiring temporary drivers, renting equipment, or contracting jobs limits their risk and exposure in the event of an accident (Tikriti 2015) while also not risking heavy investments that may not amortize. However, such practices have been shown to decrease safety due to recently hired truck drivers and their route unfamiliarity (Brown 1986; Staplin & Gish 2005; Belzer et al. 2014), different maintenance practices for leased equipment (Yeh et al. 2009). Thus, in addition to the fatigue aspects of safety, there are other safety-related, unintended consequences of HOS regulations.

In summary, fatigue and accidents may not be reduced by regulatory policy because of the effects on truck driver flexibility; because increased flexibility has been found to increase driver safety (Mackie & Miller 1978; Griffin et al. 1992; Jensen & Dahl 2009). Flexible schedules increase truck safety by providing truck drivers and truck dispatchers ample time and choices to account for fatigue level, congestion, weather, and loading requirements (Braver et al 1992).

Substitution and/or Elimination

As this research has shown, there are drastic differences in average daily driving hours under the different HOS regulations (see Figure 9, Figure 12 , Figure 13, and Figure 14), which directly relates to miles driven. Most truck drivers are paid by the mile, which is a major reason truck drivers prefer to not just be on duty, but to drive efficiently. Similarly, truck companies need to move goods (a function of distance), which also directly relates to hours driven (Williamson and Friswell, 2013). Generally, if truck drivers are on duty but not driving, they are loading or unloading their trucks. There are strong economic pressures to minimize the loading and unloading times; and truck drivers are continually looking to hasten their loading and unloading times to eliminate the time spent not driving (Morrow & Crum 2004; Duke et al. 2010). This can lead to less secure loads and possible safety implications (McKnight & Bahouth 2009). For example, HOS regulations create pressure for drivers to focus on maximizing their precious driving time under a continuously accumulating 14-hour duty clock, by rushing loading and unloading times. Such rushing can increase driver stress and fatigue. The effects of driver involvement in loading/unloading are mixed: initially, alertness may be improved but these effects wear off quickly and contribute to greater driver fatigue, especially during long duty days (Barns, 2000). Outsourcing these loading and unloading duties to someone other than the driver (as a form of substitution) may not only prevent improper loading, but may also decrease the overall fatigue of truck drivers; thereby, improving the performance of the truck driver's perishable time.

Truck drivers have seen a decrease in fatigue levels through other substitution effects. Information technology (IT) has enabled truck drivers to seamlessly take care of non-driving duties (Kettinger et al. 2012). Some of these non-driving duties have already been researched and indicate a growing trend of substitution: dispatcher communication and tracking systems for driver scheduling (Zohar et al. 2014); GPS technology for routes (Towns & Cobb 2012); and IT in truck parking (Sándor & Csiszár 2013). IT substitutions are even more critical for truck drivers that approach their HOS limits and potentially become perishable (Woensel et al. 2007). These IT substitutions have not only increased the efficiency of truck drivers perishable driving time, but they have also reduced the stress and fatigue that is associated with a higher potential for accidents (Min 2009b). Our research indicates that substitution and or elimination tactic of perishability is therefore a critical component of increasing the effectiveness and efficiency of truck driver's perishable time.

FIFO/LIFO

The concepts of FIFO and LIFO can also increase the total capacity for truck drivers and truck driving companies. Once truck drivers begin their duty day, it is critical that they are handled under the FIFO model because of the continuously accumulating 14-hour daily constraint. FIFO minimizes the expected obsolescence. Research has found that implementing FIFO policies for *perishable products* can minimize expired items by as much as 40 percent (Broekmeulen & Donselaar 2007). The results of this research reveal that this tactic may provide similar average daily driving hour benefits for *truck drivers* (a special type of perishable inventory). Using FIFO allows drivers to attain the highest average daily driving times shown in Figure 9 Maximum Average Daily Driving Hours under Various HOS regulations for Drivers Following a Consistent Schedulewhereas using LIFO results in fewer hours but greater perishable time with respect to the individual.

Sometimes, however, in order to ensure delivery of high valued goods, the policy of LIFO may be more appropriate. If the product has greater value than the perishable time of the truck driver, it is appropriate to employ LIFO to ensure product delivery. Less predictable factors such as weather, congestion, and maintenance issues necessitate utilizing a driver with the most available duty time in order to ensure timely delivery.

Regulations can lead to increased fatigue by altering the utilization of FIFO and LIFO. For example, the 1 restart per 168 hours restriction with the 1 am to 5 am provision was shown to provide great incentive to alter a schedule in order to minimize the total restart hours by 71 percent (see totalRestartHours Figure 12). However, a restart does not necessarily indicate a well-rested driver. Our analysis has shown that compliance with the regulations and restrictions can lead to a significant change in a driver's normal circadian rhythm. These circadian rhythm changes can cause safe-driving-perishability in terms of fatigue well before they reach their duty or driving hour limitations. Crum and Morrow (2002) found that the single most important factor in truck-related accidents was when the truck driver started the work week tired. Thus, it is important to consider other variables (such as circadian rhythm swaps and fatigue) than simply how many driving hours or duty hours a driver has remaining when making FIFO and LIFO decisions.

Heterogeneous: Not all drivers are created equal

Perishability occurs in part due to HOS regulations but also because of a driver's abilities. As previously stated, even though truck drivers may have the same hours available, they may not perform their duties equally. Studies have found that high body mass index (Wiegand et al. 2009), high blood pressure (Korelitz et al., 1993), and poor physical and mental shape (Taylor & Dorn 2006) all increase truck driver fatigue and the likelihood of an accident. In fact, Stoohs et al. (1994) found that obese truck drivers (who have high rates of sleep disorders) had a two-fold higher accident rate. Because not all drivers are the same, it is paramount for drivers to understand their own physical and mental limits.

This research has shown that by switching schedules (daily or weekly) can increase average daily driving hours but also alters the driver's schedule quite significantly. There are three main ways that drivers can switch their schedules: 1) increase the number of driving periods within a 24 hour period, 2) change the end time prior to the beginning of the 1 am to 5 am provision, and 3) change the preference start time after the 1 am to 5 am provision requirements are met. Utilizing these methods correctly may result in a daily driving average increase of 29 percent (see Figure 15). However, these alterations in schedules can have various negative influences on drivers' abilities. Research has found that changes in driving patterns have been shown to create more fatigue and increase the accident rate (Salomon & Mokhtarian 1997; Mackie & Miller 1978). A recent study by the American Transportation Research Institute showed that of the surveyed drivers, 66.3 percent indicated more fatigue of which 27.8 percent indicated much more fatigue due to the HOS change in July of 2013 (Short, 2013). Short found that 20.1 percent of truck drivers adjusted their start times, 15.6 percent adjusted their end times, and 18.9 percent adjusted their overall schedule. With changes in schedules and circadian rhythm, there is a greater chance of fatigue and possible accident (Harris 1977). Our results show why schedules are changed.

Long Term Plan

This research revealed two aspects regarding HOS regulations: 1) HOS regulatory policy is uncertain (see Figure 7), and 2) HOS regulations vary highly with respect to average daily driving hours that can be achieved based on the different restrictions and provisions (see Table 4 History of HOS). When there are frequent and large regulatory changes there is an increase in investment risk that decreases the probability of company investment (Luo 2004; Holcomb et al. 2014; Short 2013). A decrease in investment occurs when the long-term plan is uncertain, which diminishes investments in higher quality tractors and better-trained truck drivers; thus, investments in safety will ultimately be postponed (Marcus & Kaufman 1986). Moreover, attempting to invest in driver training, in such a high-turnover industry, is risky and economically challenging (Staplin & Gish 2005). Not only are safety investments postponed, but research has also found that in an uncertain regulatory environment capital is diverted to lobbying efforts (Rothaermel & Hill 2005).

The number of truck drivers and trucks, as well as the number and location of distribution centers, rest-stops, and loading docks, are but a few of the elements to consider when creating a long-term plan. These elements often need time to adapt and stabilize after regulatory changes are made. The frequent HOS regulatory changes, combined with the magnitude of change with respect to average daily driving hours disrupts the long-term plan and destabilizes balance in the trucking industry. For instance, the 1 restart per 168 hours HOS regulation has reduced the total time that a truck driver can operate from 82 hours to less than 70-hours per week, a 14.6 percent decrease in truck driver duty hours (FMSCA 2015). Second, shipping routes and distribution centers are often set based on set miles that truck drivers were capable of driving when that route or distribution center was created. Changing the capacity of the truck driver influences many logistical functions such as just in time (JIT) (Tommelein & Li 1999), economic order quantity (EOQ) modelling (Hahm & Yano 1995; Liao & Chih-Hsiung 1991; Burns & Hall 1985); supply chain management (SCM) vulnerability and risks (Stecke & Kumar 2009) and many more.

Conclusions

Overall, this research presented and applied perishable inventory theory and its associated tactics to the truck driving industry. The applied tactics in this research were capacity, flexibility, substitution and or elimination, FIFO or LFIO, heterogeneity, and planning. This research found great capacity differences in the various HOS regulations based on the exhaustive enumeration method, which may result in less safety due to future investments and planning in the truck driving industry. This research also found that restrictions limit the flexibility of truck drivers, which has unintended consequences such as increased congestion, or avoiding resting when tired; both of which have major safety implications. Additionally, this research showed how capacity can be increased through daily and weekly schedule changes, which, based upon the heterogeneity capability of the truck driver, may have negative safety implications. Further complicating these tactics of perishability are the frequent HOS changes, which further destabilizes the industry. Analyzing HOS through the exhaustive enumeration technique and viewing the HOS regulatory constantly changing regulations through the lens of perishable inventory theory, HOS regulations have some major negative safety implications to truck drivers currently and to the truck driving industry in the future. Future unintended consequences can be avoided by following this researches approach and method prior to implementation of future regulations.

Limitations and Future Research

As in all studies, there are limitations. The limitations of this study provide potential future research opportunities. This research provides a theoretical lens and optimization based on EE. While this approach confirms or supports actual observations of truck drivers made by other researchers, truck drivers are not a primary data source for this research. Truck drivers could and should be asked directly about these perishability concepts and tactics in future research. Surveys analyzing truck companies and drivers, pre and post HOS changes, with respect to the concepts of perishable inventory theory could establish greater credibility for the theoretical foundation presented in this research. Such research would provide greater insight into and evidence of the actual safety implications of the current regulatory environment.

Additional research is needed in coalescing regulators and truck industry experts with respect to safety as part of the field of managerial controls (Miller & Saldanha 2013) and in order to ensure wiser regulatory policies (Breyer 1986). Moreover, future research should look at directly measuring driver fatigue, through technologies such as the "sleepalyzer" (Williams et al. 2012, p.120), so that those direct measurements can be used to develop direct regulations, instead of indirect regulations that hope fatigued driving does not occur.

Theoretical Contributions

This research has expanded the realm of the theory of research dealing with perishability by incorporating perishability more broadly into the service sector and specifically into the truck driving industry. Moreover, by demonstrating that truck drivers' time is perishable with respect to deterioration (fatigue) and obsolescence due to HOS regulations, this research has provided ample evidence as to the merit of this theory within the truck driving industry. This research has brought together tactics from Perishable Inventory Theory, Perishable Asset Revenue Model, Deteriorating Theory, and Yield Management and applied them to truck driver's perishable time. Furthermore, the analysis found that the regulatory environment is not only currently in a state of change but also the changes have dramatic impact on the tactic of capacity for truck drivers. The combination of these two regulatory challenges may result in safety implications that are explained through the other tactics of perishability – flexibility, and planning. Truck companies, through other different tactics of perishability (FIFO and LIFO, substitution and or elimination) may can increase capacity through proper planning of truck driver's perishable time. The tactic of heterogeneity was used to demonstrate that although truck drivers become obsolete at the same regulated time restrictions (due to HOS regulations), they deteriorate with respect to their driving skills very differently (due to personal fatigue related factors). From these tactics for dealing with truck driver's perishable time, greater clarity is presented to understanding this very complex problem of how to regulate truck driving in order to improve motorist's safety.

Managerial Contributions

This research has shown that the truck driving industry is in turbulent times due to the frequency of regulatory changes and the magnitude of each change. By understanding and following the many tactics of perishability, the manager will be able to optimize the average daily driving hours, service levels, and truck driver safety, whatever regulation happens to be in place.

Capacity in the truck industry should be at the forefront of any manger or owner-operator. Although optimizing the miles driven may result in the most revenue, it does not necessarily translate into the most profit. Rather, managers and owner-operators should consider developing a long-term plan that not only considers equipment and personnel but also the current regulatory environment and its subsequent impact on their business. Since the regulatory environment is uncertain, managers should consider reducing their risk by outsourcing (i.e., hiring temporary drivers, leasing equipment, and outsourcing maintenance) rather than making investments directly in these assets that may not amortize. If the regulatory environment were to become more stable, less risk would be imposed on managers and owner-operators enabling them to have greater confidence in direct investments (insourcing) in personnel and equipment.

Managers and owner-operators should also consider that investments can be made in other areas besides truck drivers and trucks. Investments can be made into assets or processes that eliminate non-driving time for truck drivers thereby making them more efficient. Substitution investments can be made into technologies that better enable truck drivers to accomplish their tasks in a more efficient and productive manner as well as reducing stress and fatigue. These substitution investments decrease the variability of the workforce, which in turn enables the tactic of flexibility to flourish. Proportioning the right amount of flexibility into the system to account for congestion, weather, maintenance and other factors is improved when processes are streamlined. Unfortunately, some regulations greatly limit the flexibility of truck drivers' time. Companies employing truck drivers, owner-operators, and dispatchers should seek to understand the impact of these regulations and their negative consequences in order to ensure safe sustainable practices. They should also realize the capabilities of each driver because they are not all the same and safety is highly dependent upon their heterogeneous abilities under challenging situations. While some truck drivers may be able to drive maximum hours and switch weekly schedules (and circadian rhythms) on a regular basis without experiencing perishability with respect to their driving skills, other drivers may become perishable after their first 7 hours. Once identified, these heterogeneous abilities in drivers can be used advantageously by matching drivers to certain jobs (using either FIFO or LIFO), thereby maximizing the workforce while minimizing safety incidents. Truck drivers who have higher abilities may be better used under the FIFO model ensuring non-obsolescence of their perishable time, based on HOS regulations, while drivers with lesser abilities can be used under the LIFO model ensuring their perishability does not result from fatigue.

Legislative Contributions

Policy makers can use the exhaustive enumeration (EE) approach and the theory of perishable resources, as this research has done, to better understand how new regulations will affect the industry. The EE approach is low-cost and involves relatively simple calculations for a single regulation when comparing to existing or previous regulations in order to see the impact on the truck industry prior to its implementation. Furthermore, this technique will provide the different capacities, which will illustrate the different consequences and incentives that may result from the implementation of the regulation; thus, avoiding the "unintended consequences" that sometimes follows regulation reform. Finally, policy makers should also consider utilizing the tactics presented in this research to fully understand the many possible ramifications to safety while regulating truck drivers' perishable time.

IV. An Exploratory Study of Hours of Service and its Safety Impact on Motorists

Abstract

In July 2013, the Federal Motor Safety Carrier Association (FMSCA) revised its Hours of Service (HOS) regulatory policy, which restricts the number of duty and driving hours a truck driver can operate. The revision changed the unlimited restart provision by restricting it to 1 restart per 168 hours (1 week) and added that the restart must span two consecutive 1 am to 5 am periods. Lawmakers suspended these two aspects of the restart provision in the Consolidated and Further Continuing Appropriations act on December 16, 2014 until more analysis was completed on the efficacy of these regulations due to unintended consequences that allegedly negatively affected motorist's safety. Countering truck driver fatigue is an important issue and an extremely difficult task because of the many confounding aspects that can cause fatigue. The new regulation set forth in July 2013, was supposed to lessen fatigue and thus reduce accidents caused by truck drivers. The current HOS regulation was in place for approximately 16 months, producing enough data for a statistical analysis of its effects on truck driver safety. This research found that by comparing truck driving safety data prior to the change in July of 2013 (the unlimited restart provision) to truck driving safety data during the enactment of the 1 restart per 168-hour restriction and 1 am to 5 am provision, that the percent of accidents caused by truck drivers did not decrease. Furthermore, this research found that the HOS changes implemented on July 1, 2013 have not led to a change in the continuing downward trend in accidents involved and caused by truck drivers. These results suggest that other factors appear to be linked to motorists' safety, rather than the updated HOS regulation.

Introduction

Trucks are used to haul goods more than any other mode of transportation. In fact, 73.1 percent of value and 71.3 percent of volume of US domestic goods are shipped by trucks (US Census Bureau 2015). Trucks transport a large portion of US shipped goods, and truck drivers are responsible for a large number of crashes and fatalities. Pritchard (2010) found that there are about 5,000 fatal crashes involving trucks per year resulting in social costs greater than 32 billion dollars. Many of these accidents have been caused by fatigued truck drivers, which could have been prevented with proper rest and truck driver awareness (Quan et al. 2015). The Federal Motor Carrier Safety Administration (FMSCA) has instituted measures that restrict the driving and duty hours of truck drivers to promote safety and minimize any negative economic impact on the commercial motor vehicle industry.

FMSCA controls the duty and driving time limits of truck drivers through Hours of Service (HOS) regulations. HOS regulations restrict the number of hours a truck driver can operate in order to reduce fatigue related accidents. These regulations have changed over the years due to regulatory agencies attempting to balance fatigue related accidents and economic impact (see Table 8). In 2003, FMSCA introduced a restart provision to the HOS regulations, which allowed truck drivers to reset their duty time log back to zero as long as they took 34 consecutive hours off duty. In 2013, FMSCA altered the restart provision, which changed the amount of restarts from unlimited to 1 restart per 168-hours and included that the 34 cumulative hours off must also occur over two consecutive 1 am to 5 am periods.

Table 8 History of Hours of Service Changes

Year Changed	1938	1939	1962	2003	2005	2013	2014
Driving Hours	**12**	**10**	10	**11**	11	11	11
On-Duty Hours	**15**	**N/A**	N/A	**14**	14	14	14
Max Daily Work	**12**	**N/A**	N/A	N/A	N/A	N/A	N/A
Off-Duty Hours	**9**	**8**	8	**10**	10	10	10
Duty Cycle	**24**	24	**N/A**	N/A	N/A	N/A	N/A
60 Hour (7-day)	**60**	60	60	60	60	60	60
70 Hour (8-day)	**70**	70	70	70	70	70	70
Break						**≥8**	≥8
Restart				**≥34**	≥34	≥34	≥34
Number of Restarts						**1 Per 168 Hrs**	**N/A**
1 am to 5 am						**≥2**	**N/A**
Sleeper Berths Split Sleep				**≥2 hrs**	**≥8 hrs**	≥8 hrs	≥8 hrs
Changes	**7**	**4**	**1**	**5**	**1**	**3**	**2**

There have been conflicting claims about the effectiveness of these recent HOS regulation changes. Some trucking unions and some members of Congress have claimed negative safety implications due to prolonged traffic congestion during daytime hours and increased fatigue (Ferro 2014; Short 2013). Conversely, legislative branch members and research has claimed that the HOS revision has decreased accidents, reduced damage, and most importantly, saved lives (Ferro 2014; Chen et al. 2015; FMSCA 2010).

Although it is clear that driver fatigue is dangerous and has been linked to higher accident rates (Dinges 1995; Mackie & Miller 1978; Williamson & Friswell 2013; Summala & Mikkola 1994; Zhu & Srinivasan 2011), the effectiveness of HOS regulatory policy on reducing fatigue and making roads safer is still unclear (Arnold et al. 1997; Min 2009b). Research has found that many drivers actually begin their driving periods fatigued, indicating that HOS may restrict the number of operating hours but does not directly reduce fatigue or ensure alert truck drivers (Abrams et al. 1997).

More specifically, these two restart changes (1 restart per 168 hours restriction and the 1 am to 5 am provision) that have been suspended, until more research is conducted, are believed by some to increase accident rates due to shifting truck drivers operational times to more congested periods (Short & Murray 2014; Ferro 2014; Federal Motor Carrier Safety Administration 2011). Congress was set to reevaluate these two suspended restart changes, on September 30th of 2015 or after FMSCA finishes their studies revealing the HOS 1 per 168-hour restart and 1 am to 5 am provision efficacy.

This research investigates the safety efficacy of the 1 restart per 168-hour restriction and 1 am to 5 am provision that was enacted in July of 2013 through parametric and non-parametric statistical analysis on accidents involving trucks within the state of Ohio. This research analyzes Ohio's accident data involving truck drivers and extrapolates these findings to the US as a whole. This research compares the accidents involving trucks over two-time periods: 1) July 2009 to July 2013 – a period prior to the increase in restart restrictions and 2) July 2013 to July 2014 – a period in which the 1 restart per 168-hour restriction and 1 am to 5 am provision were in place. Since these are the main aspects of

HOS regulations that changed between these two-time periods, this research aims to discover how the restart changes affected truck drivers and their accident rate in Ohio.

The regulatory policy levied on the trucking industry has significant managerial, governance, and societal implications that may change driving safety for motorists. This research first details the history of HOS and briefly discusses the most recent changes to HOS. Then the methodology section provides the details of the analysis that was performed using the Ohio data followed by a discussion of the relevant findings. Finally, some concluding remarks and suggestions for future research are presented.

Literature Review

Hours of Service (HOS) Background

Federal Motor Safety Carrier Association (FMSCA) establishes HOS regulations for truck drivers. These regulations stipulate the maximum duty and driving hours of truck drivers. Moreover, HOS rules limit both daily and weekly duty and driving hours of truck drivers. Government agencies have stated that regulation in the trucking industry is important because of the increased potential of an accident that occurs as truck drivers work long hours (FMSCA 2015). Previous research has also filled gaps regarding the source of truck driver accidents. Most of this research has measured the effects of singular restrictions and accidents involving trucks with respect to fatigue, some examples of effects include: multi-day driving patterns (Kaneko & Jovanis 1992), starting fatigue level (M. R. Crum & Morrow 2002), driving hours per day (Hanowski et al. 2009; Soccolich et al. 2013; Williamson et al. 2011), driving time of day (Blower & Campbell 1998), breaks (Chen & Xie 2014a), sleeper-berths (Hertz 1988), truck miles (Lyman & Braver 2003; Joshua & Garber 1990; Jovanis &

Chang 1986), truck driver health (Anderson et al. 2012; Stoohs et al. 1994), and regulation enforcement improvements due to Electronic On-Board Recorders (Cantor et al. 2009).

These research efforts and others have been influential in changes that have been made to HOS regulations. The following section provides a historical perspective of some of these HOS changes.

History of Hours of Service

In an effort to mitigate fatigue-related accidents involving long-haul truck drivers, the Interstate Commerce Commission (ICC) established HOS regulation in 1938 ("Federal Register, Volume 65 Issue 85", 2000). By 1939, regulations restricted truck driving to ten-hour increments and mandated rest periods of eight hours between those increments ("Federal Register, Volume 65 Issue 85", 2000). The policy was controversial for some drivers and government officials. A FMSCA (2000) report quotes an ICC official who objected to the proposed HOS regulation in 1937:

> We have no control over the manner in which a driver may spend his time off-duty, although some of his spare time activities may tire him as much as any work would do. We can only emphasize, by this comment, the responsibility which is the driver's own to assure himself of adequate rest and sleep, in the time available for this purpose, to ensure safety of his driving, and likewise the employer's responsibility to see that his drivers report for work in fit condition (ICC, 1937).

The HOS policy remained predominantly unchanged for the next 60 years (Hall & Mukherjee 2008). Subsequent revisions to the policy, which were implemented in January of 2004, made three main changes with respect to time: 1) driving time increased to 11 hour increments, 2) duty hour restriction changed to a maximum of 14 hours on-duty and 10 hours off-duty before coming on-duty again, and 3) was provided a 34-hour restart period (Federal

Motor Carrier Safety Administration 2016). These revisions occurred because there was "general recognition that the existing rules for the truck industries had been well implemented before there had been a clear scientific understanding of fatigue causal factors (e.g., time of day, amount and timing of sleep, time awake, and time on task)" (Federal Motor Carrier Safety Administration 2003, p.22458). FMSCA brought in experts and relied heavily on fatigue research in order to update these HOS regulations.

History of the Restart Provision

The 34-hour unlimited restart provision for all commercial motor vehicles was instituted in 2003 in order to reduce the effect of cumulative fatigue and prevent fatigue-related crashes. However, FMSCA later found that the 34-hour unlimited restart provision provided the ability for truck drivers to attain more hours than 70 hours per week, which was previously not possible because of the 70-hour restriction. The restart enabled truck drivers to operate 5 days, on a maximum schedule, and take a restart on the 6th day and drive again on the 7th day, enabling truck drivers to attain approximately 82 hours per 7-day period (Federal Motor Carrier Safety Administration 2011). This prompted FMSCA to limit the restart provision.

Further restart limitations were implemented on July of 2013. The goal of the changed regulations was to lessen long work hours and decrease fatigue-related crashes and long-term health problems for truck drivers (Federal Motor Carrier Safety Administration 2003; Rodriguez et al. 2006; Dingus et al. 2006). The additional restart restrictions included two main changes: 1) required that the restart restriction time covers from 1 a.m. to 5 a.m. for two consecutive nights, and 2) limited drivers to 1 restart per 168-hour interval.

The additional restart restrictions were predicted to further reduce the continuing downward trend in safety-related accidents by preventing an additional 1,400 crashes, 560 injuries, and 19 deaths per annum (Federal Motor Carrier Safety Administration 2016). These two restart provisions were suspended due to growing concerns of unintended consequences in December of 2014 until September 2015, or until further research was accomplished providing data on the efficacy of these provisions. The 34-hour unlimited restart provision was reconstituted in December of 2014.

1 Restart per 168-hours and 1 a.m. to 5 a.m. Provision

One of the major aspects of the HOS regulations is the number of restarts a driver can utilize. In July 2013, the restart changed from unlimited to only one restart per 168-hour period. The ability to take more than one restart per 168-hour period provided drivers with the opportunity to be on duty more hours than the 60 hours per 7 days provision or 70 hours per 8 days provision. Using unlimited restarts, under the 60-hour provision, a truck driver could obtain 78.4 duty hours per week. Under the 70-hour provision, using unlimited restarts, a truck driver could obtain 81.66 duty hours per week. The updated HOS regulation, which limits a driver to one restart per 168-hour period, decreases the total number of duty hours to 70 for the 70-hour provision and to 60 for the 60-hour provision. This is approximately a 16.6 percent reduction for the 70-hour provision, and a 30 percent reduction for the 60-hour provision.

While more total duty hours within a given driving period has been shown to lead to more accidents (Cantor et al. 2010; Harris 1977; Soccolich et al. 2013; Wiegand et al. 2009), no studies have been done on the safety implications of multiple restart periods and its effect on truck driver fatigue. Since drivers should be the most rested immediately following a restart period, it could be assumed that more restarts during a given period may actually increase driver safety. However, FMSCA limited the restarts to 1 per 168 hours because of excessive buildup of on-duty hours that can occur before and after a restart is taken, without sufficient evidence regarding fatigue and use of multiple restarts (Federal Motor Carrier Safety Administration 2011; Ferro 2014).

In conjunction with the 1 restart per 168 hour restriction, FMSCA instituted the 1 a.m. to 5 a.m. provision. Previous iterations of the HOS regulation have restricted the amount of driving and duty time for a truck driver, but regulations have never stipulated the exact time of day during which the restart time must occur (Federal Motor Carrier Safety Administration, 2016).

The 1 a.m. to 5 a.m. provision was adopted by FMSCA due to research indicating that the most effective sleep occurs at 2 a.m. to 5 a.m., thus ensuring time off during the major circadian low for the majority of truck drivers (Folkard & Tucker 2003; Dongen & Dinges 2005). Research has also found that sleep at night for daytime workers is better than sleep during the day for nighttime workers (Lavie 1986; Van Dongen & Mollicone 2014; McCartt et al. 2000).

By implementing the 1 am to 5 am provision, truck drivers who drive at night may also switch schedules and begin driving during the day to correspond with the time of the provision. This may improve safety, because research has found that when removing traffic density or congestion, driving at night is 10 times as dangerous than during the day for truck drivers (Lavie 1986; Horne & Reyner 1995). Although night-time driving is dangerous due to potential for increased fatigue and darkness, day-time driving is dangerous due to increased congestion.

Shifting more drivers to the day leads to increased congestion, which has been shown to impact motorist's safety. First, increased congestion reduces miles driven, thereby making drivers operate more daily hours (Kok et al. 2012) and exposing the driver's to the higher risks associated with longer days. Second, research has shown that traffic flow was the single most important factor (more than circadian rhythm) in determining accident rates (Dingus et al. 2006). Higher disparity of speed differences between vehicle types is a major reason for increased accident rates, due to the acceleration and deceleration differences between large and small vehicles in congestion (Chen et al. 2011; Beilock 1995; McCorry & Murray 1993; Peeta et al. 2005; Neeley & Richardson 2009). Basically, as congestion increases, the rate of accidents also increases (Kononov et al. 2008). Campbell (1995) suggested providing greater incentives for truck drivers to operate outside the congested periods due to increased safety for trucks and motorists. However, FMSCA's 1 am to 5 am provision resulted in an incentive to the drive during congested periods (Commerce Appropriations Act, 2014).

One of the other possible consequences of the 1 am to 5 am was that nighttime drivers may shift their schedule to minimize the restart period duration and increase operating hours (Short & Murray 2014; Federal Motor Carrier Safety Administration 2011). FMSCA also stated that nighttime drivers will generally migrate to daytime schedules due to family life and events occurring at home since they do not want to sleep when everyone else is awake (Federal Motor Carrier Safety Administration, 2011). Shifting schedules has been found to be a major cause of truck driver fatigue (Åkerstedt et al. 2008; Williamson et al. 2011; Rio-Bermudez et al. 2014; Dongen & Dinges 2005).

The 1 a.m. to 5 a.m. stipulation also becomes challenging because of the different and numerous time zones in which truck drivers operate. The restart period time is based on the truck driver's home terminal time and not their current location (FMSCA, 2016). For example, a truck driver from Indiana driving to Nevada is mandated to rest during the restart period from the Nevada local time of 10 p.m. to 2 a.m. Conversely, a truck driver from Nevada driving to Indiana is mandated to rest during the restart period from the Indiana local time of 4 a.m. to 8 a.m., which may no longer span the most effective sleep time (2 am to 5 am). The 1 a.m. to 5 a.m. stipulation becomes even more arbitrary for truck drivers who are away from their home terminal time for long periods. Also, tracking home terminal times and local times, especially when crossing multiple time zones, becomes onerous for the truck driver and becomes the source of potential, accidental record keeping violations.

The safety impact of the 1 restart per 168 hours and the 1 a.m. to 5 a.m. provision to truck drivers is difficult to discern because of the multiple effects that are occurring that were previously discussed: a likely increase in truck traffic during congested period, changes in truck driver circadian rhythm, a possible decrease in driving hours and night-time driving, and an unknown safety implications of the 1 am to 5 am home terminal time. Unfortunately, FMSCA adopted the 1 restart per 168 hour restriction and the 1 a.m. to 5 a.m. provision prior to completing necessary research, which would have greatly aided in understanding the possible safety implications of changing HOS regulations. Representative Richard Hanna (Vice Chair for Highways and Transit) stated "The intent is clearly that the study be completed before the rule is enacted," at which time the study was anticipated to be completed approximately one year after the change was ratified (Ferro, 2014).

Mandated 30-Minute Break Provision

The 30-minute rest break is an additional HOS regulation that was adopted in July of 2013. The 30-minute break was not suspended in December of 2014, and continues to remain in effect. Although the schedule placement of the 30-minute break has some flexibility, it must occur within the first 8 hours of driving. In order to count as a 30-minute break, the truck driver must not be working in any capacity, but can use that time for such things as eating, resting, or exercising (FMSCA, 2016).

Blanco et al. (2011) researched rest breaks, as part of a FMSCA-sponsored study, providing the legislative branch the conclusions needed to enact the 30-minute break provision. They noted that of the 97 drivers monitored, their duty day was comprised of 66 percent driving, 23 percent non-driving work, and 11 percent resting. They also found that the rate of accidents decreased immediately following the break. However, they also observed that the rate of accidents were highest at the end of the driving period. Some research suggests that the addition of the break, which causes the overall duty day to be lengthened, may lead to more net accidents (Short 2013; Chen & Xie 2014b). This suggests that some of the benefits of the break are offset by an increase in accidents due to the extension of the driving period.

Another finding that challenges the 30-minute break provision is the ability to enforce this regulation (Short, 2013). This rule ensures that the truck is not continually driven, due to the electronic logbook, but it cannot guarantee that the driver is not performing duty-related activities. Blanco et al. (2011) found that off-duty breaks were best, but any break that was different from driving also provided an accident rate reduction.

Unintended Consequences of Regulatory Policy

Balancing many unique work and lifestyle demands makes a “one-size-fits-all” approach to regulation difficult. When policies are made in order to curtail a dangerous event or certain behavior, other unintended problems may arise. Senator Collins stated, “it has become clear that the rules have had unintended consequences that are not in the best interest of carriers, shippers and the public” (Patton 2014).

Sometimes regulations intending to reduce fatigue may actually increase it for some truck drivers. A 2008 report to FMSCA found no evidence suggesting a 2003 rule change decreased the number of deaths caused by large truck crashes and stated that it may have actually increased the number of deaths (FMSCA, 2015; Short, 2013; Min, 2009; ATA, 2013; Holcomb, 2014). Simply put, HOS regulation does not ensure well-rested drivers; it ensures specified off-duty times and driving/duty time limits.

There are three unintended consequences of HOS: 1) a switching from nighttime driving to daytime driving, 2) an increase in the stress levels of drivers, and 3) a need for more truck drivers (Ferro 2014; Short & Murray 2014; Brewster & Short 2014; Goel 2014). Concerning switching schedules, FMSCA (2016) claimed to know of no reason why truck drivers would change from driving at night to driving during the day. This claim contradicts recent studies, which found approximately 15 percent of drivers have indeed changed their schedules by switching from nighttime to daytime driving in order to work within the regulations (Fender & Pierce 2013). Changing work and sleep times have been shown to increase fatigue and the rate at which accidents occur (Rio-Bermudez et al. 2014; Åkerstedt 1998; Torregroza-Vargas et al. 2014; Goel 2014).

In addition to increasing fatigue, changing work and sleep times can increase physical, emotional, and mental stress levels for drivers (Sando et al. 2010; Chen et al. 2015). Truck drivers may also become fatigued from financial stress related to restrictive rules that are enforced by large ($2,750 per incident) fines, or pay decreases due to driving time limitations (Federal Motor Carrier Safety Administration 2016; Short 2013; Min 2009a; Holcomb et al. 2014).

The third unintended consequence of HOS is the need for more truck drivers. More restrictive HOS changes cause the loss of available man-hours, leading to an increased need for companies to hire more drivers and cancel or decline shipments (Min 2009b). Newly hired drivers will not have the same experience or training as existing drivers. This may increase the rate at which truck drivers cause accidents (Belzer et al. 2014). HOS regulations create persistent driver training and retention challenges (Belzer et al. 2014). High turnover reduces driver qualifications and route familiarity, which in turn can decrease safety.

Accident Background

Accidents per mile involving and caused by truck drivers have steadily decreased over time (Lyman & Braver 2003; Bruning 1989; Robert D Pritchard 2010). In their final rule, FMSCA (2011) reported crash rates falling well before 2004 and a general downward trend in Commercial Motor Vehicle (CMV) deaths that rose between 2003 and 2006 and then dropped in the following years. FMSCA also reported there was another subsequent drop in driver deaths in 2008, but stated that it could be due to other factors such as a weaker economy that led to reduced driving, increased seat-belt use, and better training and retaining of truck drivers. In 1975, truck crashes occurred at a rate of 5.8 per billion miles traveled

(Martinez 1997) and is now at 1.27 per billion miles traveled (National Highway Traffic Safety Administration 2016).

Although the overall number of accidents are declining per mile, there is research indicating the severity of accidents has increased due to size and speed of the trucks (Zhu & Srinivasan 2011; Duncan et al. 1998). But severity of an accident has not necessarily led to a higher percentage of fatalities, which is in part due to safety technologies that benefit all motorists (Kahane 2015). Safety technologies such as airbags (front and side), lane assist, LIDR, GPS, better maintenance of vehicles, and enhanced brakes are claimed to have saved over 328,551 lives from 1960 to 2002 (Kahane 2015). In 2014, the NHTSA found that 1,144 lives were saved among passenger vehicles in 2012 due to lane assist technologies. Drivers may also be receiving better training and awareness on factors leading to accidents such as fatigue, medication, weather conditions, traffic congestion, enabling higher quality risk-management decisions and thus a lower number of accidents caused by truck drivers.

There have been numerous studies approximating the percent of fatigue related truck accidents: 20 percent (Moonesinghe et al. 2003); 41 percent (The American Automobile Association Foundation for Traffic Safety 1985); 31 percent (NTSB 1990); 16 to 55 percent (Chang & Chien 2013). In our research, the percent provided by a FMSCA sponsored study is used, which showed that fatigue is the main cause of truck-related accidents 13 percent of time (Craft and Blower, 2007).

Other Changes in Ohio Law

Other factors that may also have an impact on truck accidents during the periods studied are other changes to laws and regulations for vehicles in Ohio. There are two regulations that are thus discussed: speed limit changes and distracted driving laws implemented during the period studied (2009-2014). In the state of Ohio, House Bill 395 passed increasing speed limits for 607 miles of highways and freeways across Ohio, and also aligned truck speeds to the same speed as other motor vehicles (Grant 2013). Studies have found increased crash rates and severity due to increased speeds; studies have also found large differences in speeds between vehicles correlate to higher crash rates (Aarts & Van Schagen 2006; Solomon 1964). However, Ohio increased speeds only on major roads. The speed limit increase in 2011 on the Ohio turnpike saw a decrease in the mean number of fatalities (Armon 2013). The Crash Risk Curve, developed by Solomon (1964), illustrated that driving at the median speed had the lowest probability of a crash. Since truck drivers had lower speed limits than that of motorists, the speed variation on roads was greater and more unsafe. Since the bill both increased the speed limit for motorists on major roads (leading to an increase in crash rates) and uniformly aligned speeds for trucks and automobiles (resulting in a reduction in crash rates), it is reasonable to assume that the speed limit changes should not have significantly changed crash rates involving trucks over the periods being studied by this research.

The second law that changed dealt with distracted driving, which has been a major concern as a causal factor in crash accidents (Dingus et al. 2006; Young et al. 2007). Ohio passed a texting law in June 2012, which was primary for drivers under 18 and secondary (meaning that officers cannot cite based only on the texting) for drivers over 18. Since truck drivers must be over 21 to drive, and research has found that secondary texting laws do not have an effect on accident rate (Abouk & Adams 2013) this law was not considered in this research.

The next section will discuss the approach used to discern the safety efficacy of the 1 restart per 168 hour restriction and the 1 am to 5 am provision aspects of the recent HOS revisions on the safety of truck drivers in Ohio.

Method

Monthly data from all 88 counties in Ohio were analyzed, providing insight into the recent changes made to HOS regulation and the associated safety implications on motorist and truck driver safety. Monthly data was used because the changes to HOS occurred in July, instead of at the start of the calendar year, January. The state of Ohio is used because of its timely compilation of motor vehicle statistics available for research and because of Ohio's similar population density, roadways, and truck routes that cause Ohio (12.05 crashes per million people) and the US (11.22 crashes per million people) to also have a similar fatality rate with respect to large truck crashes (see Figure 18).

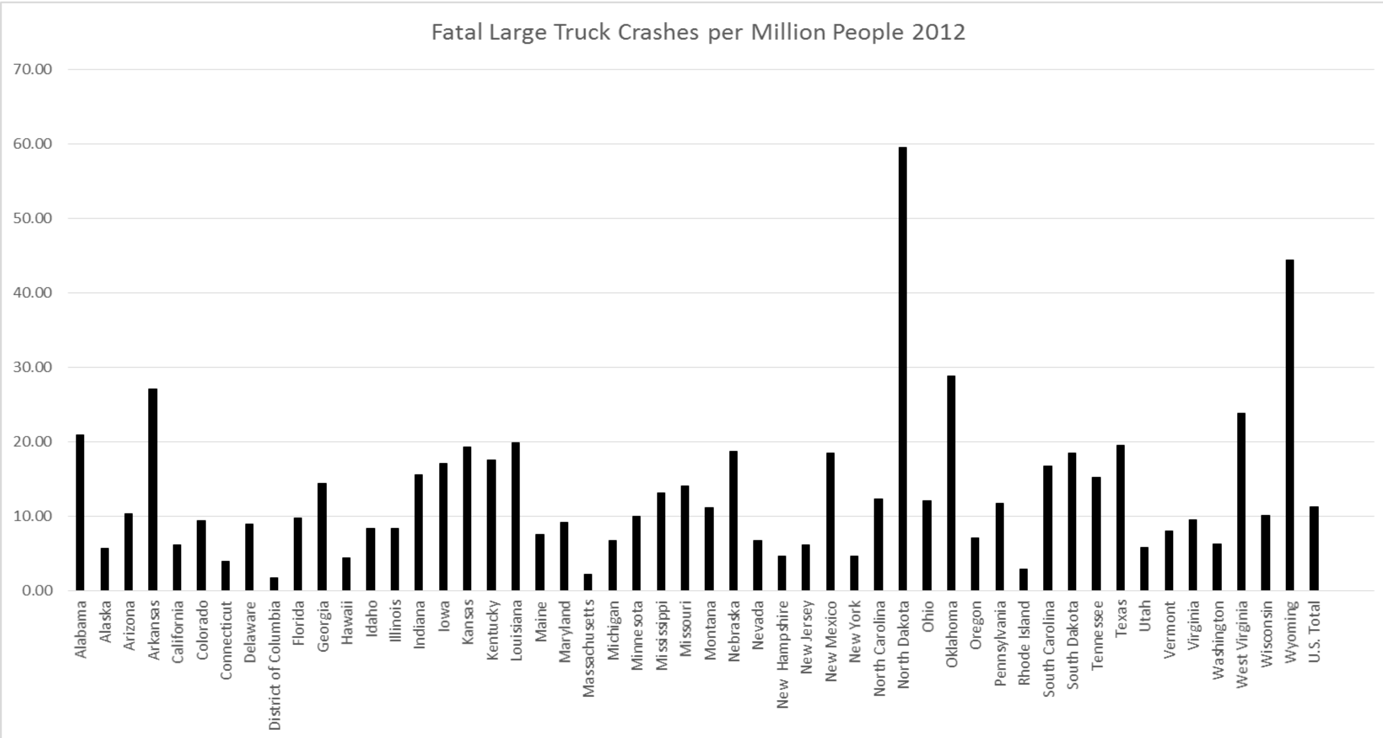


Figure 18 Truck Crash Rate and Population Density for 2012

Although Ohio's roadways or geography may be unique in the US, it does not present a problem in extrapolating Ohio's data because historical data captures any unique geography or roadway characteristics that may exist in Ohio. Also by analyzing the time in question (July 2013-June 2014) for Ohio and extrapolating upon that geographic data removes the element of change that may occur due to time (Saccomanno & Nassar 1997; Khasnabis & Ramiz-Al-Assar 1989; Gordon 1994). Regressions are created from historical accidents involving trucks that occurred in Ohio providing a consistent historical percentage, which is used to approximate the impact of HOS in the US. Data used in Ohio provides information of HOS impact in the US similar to the extrapolating work conducted by Paddock (1974) and Vogt and Bared (1998) using road and intersection data from Minnesota and Washington to build accident models; and Khattak, Schneider, and Targa (2003) who estimated risk factors in truck rollovers from police reports from North Carolina from 1996 to 1998.

A total of 60 months of retrospective data are analyzed. Since the HOS regulation was changed in July of 2013, calendar year data would not measure the correct treatments. The 12 month span from July 2013 to June of 2014 is named post-HOS data. In order to avoid seasonality fluctuations in the data, the other 48 months were grouped into four years starting in July and ending in the June (named pre-HOS data). This provides a total of five years of data that can be broken down by months, by year, and by pre- and post- HOS. Four of these five years, or 48 of the 60 months, detail accidents involving trucks regulated under the unlimited restart provision and 12 months, detail accidents involving trucks regulated under the 1 restart per 168-hour restriction combined with the 1 am to 5 am provision.

There are nine variables of interest for each month. These variables are: 1) total fatalities involving trucks, 2) total fatalities caused by truck drivers, 3) percent of fatalities caused by truck drivers, 4) total injuries involving trucks, 5) total injuries caused by truck drivers, 6) percent of injuries caused by truck drivers, 7) total property damage accidents involving trucks, 8) total property damage accidents caused by truck drivers, and 9) percent of property damage accidents caused by trucks[2]. This research examined 540 data points from this 5 year or 60 month period (60 months * 9 variables of interest = 540 data points).

[2] Accidents caused by truck drivers were determined by the investigating officer at the scene.

First, pairwise comparisons were made between the pre- and post-HOS monthly outcomes of the nine variables of interest. More specifically, for the pre-HOS data, monthly data averages (4-months of data across four years for each calendar month), standard deviations, and variances were computed and compared to the same statistical measurements against the post-HOS monthly data using the paired t-test for injuries and property damage. For fatality data, parametric assumptions were not met to conduct the paired t-test, so the non-parametric Wilcoxon Signed Rank test was applied (Hollander et al. 2013).

In order to account for any possible downward trend of accidents over the years, these comparisons were expanded to examine the differences in the variables of interest by year versus grouping them as pre- and post-HOS. Each year was now considered a treatment in analysis of the variables of interest to capture differences utilizing parametric and non-parametric testing techniques.

To examine differences between years, Analysis of Variance (ANOVA) testing was conducted followed by the post-hoc Fisher's Least Significant Difference (LSD) pairwise comparison when ANOVA parametric assumptions were met. For the assumptions, normality was assessed using the Shapiro-Wilks test (Razali & Wah 2011). Constant variance was assessed using the Bartlett test (Levene 1960); and independence was assessed via the Durbin-Watson test (Kanlayasiri & Boonmung 2007). Consequently, ANOVA was appropriate for analyzing injuries and property damage involving trucks or caused by trucks. Since the fatality data failed the test for normality, the nonparametric Friedman, Kruskal-Wallis, and subsequent post-hoc Wilcoxon Rank Sum tests were used for data relating to fatalities followed by the Wilcoxon Rank Sum test for pairwise comparisons.

Finally, utilizing data from the Department of Transportation (DoT) regarding the same types of accident involving trucks (fatalities, injury, and property damage) from 2002 until 2012 enabled regressions to project US accident types involving trucks for the time period of July 2013 to June of 2014. Three estimates emerged from each of the regressed points: 1) the predicted regressed estimate if no HOS changes occurred, 2) the corresponding projected FMSCA claim estimate, calculated as the estimate if no HOS changes occurred less the anticipated improvement by type of accident (19 fatalities, 560 injuries, and 1400 property damage), and 3) an estimate for the possible reduction of fatigue related accidents computed as deducting 13 percent from the estimate if no HOS changes occurred. These corresponding points were then analyzed against the Ohio extrapolated point, which is discussed next.

Utilizing the data from Ohio Department of Safety Statistics, accident data was collected from 2002 through 2012 regarding the same types of accidents (fatal, injury, and property damage) and modeled as a function of time (year). This regression provided the estimate of what should have occurred given no change in HOS regulation. This value was divided by the actual number of accidents, by type of accident, providing a corresponding percentage that was used to extrapolate the US estimate for the period from July 2013 to June of 2014. This approach is similar to research used by the National Highway Traffic Safety Administration (NHTSA) to gain awareness of vehicle weights or safety belt use and their relationship with fatalities (Kahane 1997).

Confidence intervals on the regression lines describing the relationship of type of accident over years were used to examine whether or not the above regression estimates predicted by FMSCA and the Ohio point estimate are within the associated confidence bounds. The magnitude of the FMSCA estimates were compared to the total US accidents, and to the total US accidents that were perhaps caused by fatigue.

Many studies compare the number of accidents to the vehicle miles traveled in order to substantiate a rate that accounts for the quantity of truck miles on the road (Forkenbrock 1999; Jovanis & Chang 1986; Miller et al. 1991). This could not be accomplished for this research because it utilized mid-year data (beginning in July and ending in June) where the VMT is reported on an annual basis. Instead, traffic, toll road (a road that drivers must pay directly to use), and gas tax revenue data were examined in order to eliminate or reduce effects from other possible influencing or confounding factors (Downs 1992). In addition, toll roads break down the vehicle class providing data on the actual vehicles on toll ways, just as gas tax revenue similarly estimates traffic congestion (Newman & Kenworthy 1989).

All analyses assumed an alpha equal 0.05 level of significance and were conducted primarily using JMPv11.0 software. Results concerning the analyses of the previously mentioned 9 variables of interest are presented in the next section.

Analysis

Pre-HOS vs. Post-HOS Analysis

Summary statistics for fatalities are shown in Table 9. Although there was a drop in fatal accidents from pre-HOS (mean 10.48 and median 10) to post-HOS (mean 9.17 and median 9.5), this decrease was not statistically significant (p-value=0.309). Incongruously, fatality accidents caused by truck drivers rose slightly from pre-HOS (mean 3 and median 3) to post-HOS (mean 3.42 and median 3). However, this increase was also not significant (p-value=0.586).

Table 9 Comparison of Pre- and Post-HOS Fatal Accidents

Causation Category	Statistical Category	PRE HOS (48 Months) July 2009 - June 2013	POST HOS (12 Months) July 2013 - June 2014	(Pre vs Post HOS) P-Value
Fatal Accidents Involving Trucks	Mean	10.48	9.17	0.309
	Standard Deviation	3.57	4.61	
	Median	10	9.5	
Fatal Accidents Caused by Truck Driver	Mean	3	3.42	0.586
	Standard Deviation	1.79	2.35	
	Median	3	3	

Conversely, paired t-tests (see Table 10 and Table 11 where significant p-values are shaded) indicate there are significant differences between pre- and post-HOS periods regarding injury and property damage accidents involving trucks. Total injury accidents decreased by a mean difference of 51.75 per month (p-value < 0.001). Furthermore, the mean number of injuries caused by truck drivers decreased by greater than 22 accidents per month (p-value = 0.007). Additionally, property damage accidents involving trucks decreased by approximately 240 per month, and by 132 property damage accidents caused by truck drivers (p-values < 0.001).

Table 10 Injury Accident Analysis

Causation Category	Statistical Category	PRE HOS (48 Months) July 2009 - June 2013	POST HOS (12 Months) July 2013 - June 2014	(Pre vs Post HOS) P-Value
Injury Accidents Involving Trucks	Mean	293.25	241.5	<0.001
	Standard Deviation	41.68	62.94	
	Median	298.5	241	
Injury Accidents Caused by Truck Driver	Mean	152.48	129.83	0.007
	Standard Deviation	24.39	28.37	
	Median	155	126.5	

Table 11 Property Damage Accident Analysis

Causation Category	Statistical Category	PRE HOS (48 Months) July 2009 - June 2013	POST HOS (12 Months) July 2013 - June 2014	(Pre vs Post HOS) P-Value
Property Accidents Involving Trucks	Mean	1178.04	937.83	<0.001
	Standard Deviation	183.66	223.77	
	Median	1174	937	
Property Accidents Caused by Truck Driver	Mean	701.29	569	<0.001
	Standard Deviation	108.82	132.83	
	Median	707	533	

12-Month Increments Analysis

In order to account more accurately for the general decreasing trend in accidents with respect to time, the 48-month block pre-HOS was broken down into four periods. Each period consists of 12 month (July to June) ranging from 2009 to 2013.

Fatal accidents caused by truck drivers were not significantly different from any other year, based on a Friedman test (p-value = 0.208), nor were fatality accidents (p-value = 0.425) as can be seen in Figure 19.

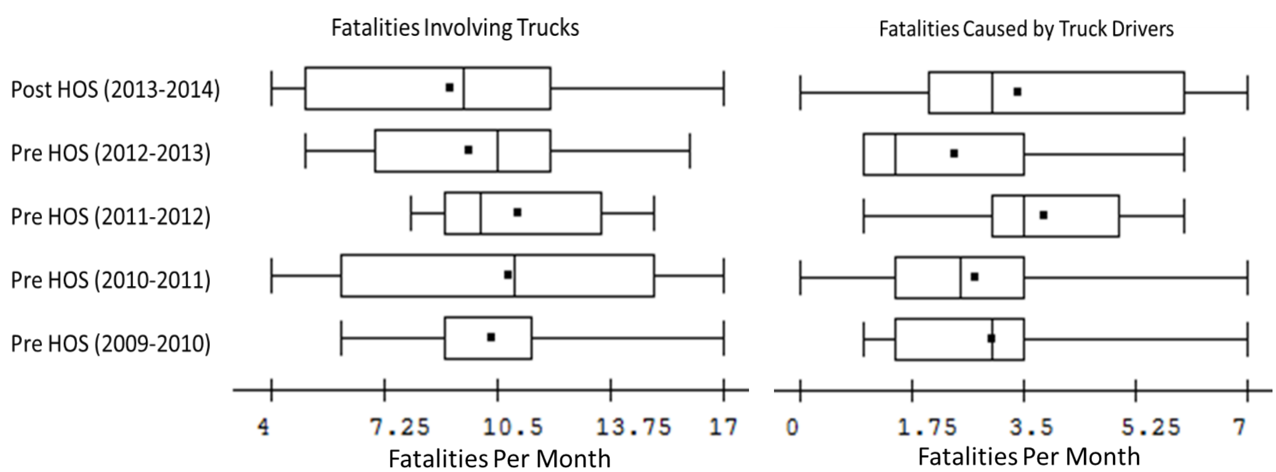


Figure 19 Fatalities Distribution Caused and Involved with Truck Drivers in Ohio

Table 12 breaks down the fatality data further by providing overall rank and p-value differences based on the Wilcoxon Signed Rank tests. Ranking similar months across the five different periods, and then taking the average rank for that specific period, provides a means for a nonparametric comparison of the data. The rank differences are the rank of the reference years subtracted by the contrasted years. Although not statistically significant, Table 12 reveals that the post-HOS for fatalities involving trucks was on average 0.41 less than the previous period (p-value = 0.59), but was 0.88 higher in regards to truck drivers (p-value = 0.25). Fatalities caused by truck drivers, in the post-HOS period, were the second highest average rank period, but were the lowest in fatalities involving trucks.

Table 12 Fatalities Involved and Caused by Trucks Contrasted by Year

		Fatality Involving a Truck			Fatality Caused by Truck		
Reference Year	Contrasted Year	Median Difference	Rank Difference	P-Value	Median Difference	Rank Difference	P-Value
July 2013-June 2014	2012-13	-1	-0.41	0.585	1.5	0.88	0.300
	2011-12	-0.5	-1.16	0.127	-0.5	-0.54	0.413
	2010-11	-1.5	-0.75	0.326	0.5	0.33	0.703
	2009-10	0.5	-0.79	0.300	0	0.38	0.703
July 2012 - June 2013	2011-12	0.5	-0.75	0.321	-2	-1.42	0.064
	2010-11	-0.5	-0.34	0.663	-1	-0.55	0.513
	2009-10	1.5	-0.38	0.623	-1.5	-0.5	0.513
July 2011 - June 2012	2010-11	-1	0.41	0.585	1	0.87	0.230
	2009-10	1	0.37	0.623	0.5	0.92	0.230
July 2010 - June 2011	2009-10	2	-0.04	0.956	-0.5	0.05	0.999

Table 13 and Table 14 depict mean differences between each 12-month period regarding injuries, and property damage. There were significant differences between means in the number of accidents of at least some of the 12-month periods (ANOVA p-value < 0.001). Shaded values indicate that the reference year is significantly different from the contrasted year. The LSD pairwise results suggest a greater mean change between larger time spans confirming a downward slope of occurrences over time. Consequently, it is more likely that the post-HOS period is most comparable to the preceding 12-month period. As such, post-HOS data is not significantly different from the previous 12-month period in terms of injury, property damage, or total accidents. As an illustration of this point, injuries caused by truck drivers during the period of July 2013- June 2014, and the previous 12 months indicates a mean difference of -3.08 at a non-significant p-value of 0.744. When comparing the July 2013-June 2014 period with the period beginning in 2011 and ending in 2012, the mean decreased by 25.42 with an associated significant p-value of <0.009. The two main concepts from these tables are: 1) there has been a downward trend in accidents involving and caused by truck drivers and 2) the post-HOS year is not significantly different from the previous year in terms of injuries, and property damage caused or involved with truck drivers. The analysis results suggest that HOS did not improve safety more than what had already been occurring.

Table 13 Injuries Involving and Caused by Trucks Contrasted by Year

		Injury Accidents			
		Involving a Truck		Caused by Truck	
Reference Year	Contrasted Year	Mean Difference	P-Value	Mean Difference	P-Value
July 2013-June 2014 (Post-HOS)	2012-13	-10.92	0.518	-3.080	0.744
	2011-12	-54.67	0.002	-25.420	0.009
	2010-11	-82.92	<.001	-38.420	<.001
	2009-10	-58.5	<.001	-23.670	0.021
July 2012 - June 2013	2011-12	-43.75	0.012	-22.330	<.001
	2010-11	-72	<.001	-35.330	0.033
	2009-10	-47.58	0.006	-20.580	0.002
July 2011 - June 2012	2010-11	-28.25	0.098	-13.000	0.172
	2009-10	-3.83	0.820	1.750	0.853
July 2010 - June 2011	2009-10	24.42	0.151	14.750	0.122

Table 14 Property Damage Involving and Caused by Trucks Contrasted by Year

		Property Damage Accidents			
		Involving a Truck		Caused by Truck	
Reference Year	Contrasted Year	Mean Difference	P-Value	Mean Difference	P-Value
July 2013-June 2014 Post-HOS	2012-13	-85.830	0.242	-46.250	0.290
	2011-12	-288.420	<.001	-170.080	<.001
	2010-11	-321.000	<.001	-178.170	<.001
	2009-10	-265.580	<.001	-134.670	0.003
July 2012 - June 2013	2011-12	-202.580	<.001	-123.830	0.006
	2010-11	-235.170	<.001	-131.920	0.004
	2009-10	-179.750	0.016	-88.420	0.046
July 2011 - June 2012	2010-11	-32.580	0.655	-8.080	0.853
	2009-10	22.830	0.754	35.420	0.417
July 2010 - June 2011	2009-10	55.420	0.448	43.500	0.320

Percent of Truck Drivers at Fault Analysis

An analysis of percentages rather than actual values associated with truck-related accidents can yield additional insights. Looking at the percentage of crashes caused by truck drivers out of the total number of crashes involving trucks provides a better comparison between years, which may involve differences attributable to features such as highway technologies, road construction, vehicle safety equipment, traffic congestion, weather, etc. Since HOS only targeted truck drivers, it would be intuitive that the percentage of truck drivers at fault would drop due to the added benefit of the safety regulation. Table 15 presents the percentage of truck drivers at fault for fatalities, injuries, and property damages involving trucks. Across all of these categories, the percentage of accidents caused by truck drivers increased during this period. This indicates that more truck drivers are responsible for accidents occurring; however, these trends were not statistically significant (p-value between 0.113 and 0.247).

Table 15 Post and Pre HOS Percent Distributions

Accident Type Caused By Truck Driver	Pre-HOS Mean% (Standard Deviation)	Post-HOS Mean% (Standard Deviation)	(Pre- vs Post-HOS Mean) P-Value
Fatal	28.28% (13.99% Std Dev)	36.72% (23.67% Std Dev)	0.114
Injury	52.04% (4.45% Std Dev)	54.46% (5.43% Std Dev)	0.113
Property Damage	58.63% (3.33% Std Dev)	60.92% (3.75% Std Dev)	0.247

Percentage data were further stratified into the five 12-month periods beginning in July and ending in June (Table 16). The percentage of truck drivers at fault increased during the post-HOS period. The post-HOS period has a higher mean across all measures than all the prior years, however, this difference was only significant for fatalities caused by truck drivers when compared to the previous year 2012-13 (p-value=0.026).

Table 16 Ohio Percent of Accidents Caused by Truck Drivers Least Significant Difference

		% Fatality Caused by Truck		% Injury Caused by Truck		% Property Damage Caused by Truck		% Total Caused by Truck	
Reference Year Post-HOS	Contrasted Year Pre-HOS	Mean Difference	P-Value	Mean Difference	P-Value	Mean Difference	P-Value	Mean Difference	P-Value
July 2013-June 2014	2012-13	13.61	0.026	1.87	0.295	0.92	0.476	1.19	0.304
	2011-12	0.9	0.881	2.2	0.220	0.53	0.681	0.79	0.491
	2010-11	11.77	0.054	2.46	0.171	1.33	0.305	1.61	0.166
	2009-10	7.46	0.217	3.15	0.080	2.38	0.069	2.52	0.031

Ohio Extrapolation to the US Analysis

Extrapolating the Ohio data to the US is important to gain insight on the impact of HOS across the US and to compare the results to FMSCA's predictions of 19 lives saved, 560 injuries prevented, and 1,400 property damage accidents avoided. US data used from 2002-2012 provided the regression data needed to estimate what the US should have seen during the period of July 2013 to June 2014 if the 1 restart per 168 hours and 1 am to 5 am was not implemented. These three estimates (fatality, injury, and property damage accidents involving trucks) are labeled US regression estimate in Table 17 HOS Analysis The associated FMSCA predictions are subtracted from these predicted estimates providing an estimate of change that the revised HOS regulations should have achieved. The next column, labeled Ohio extrapolated point on US fatalities, indicates the change extrapolated from Ohio based on multiple factors. First, three (fatality, injury, property damage) regressions were performed on accidents involving trucks in Ohio from 2002 to 2012 providing a regression estimate for July 2013 to June 2014 period if HOS did not change. Using the actual number of accidents that occurred in Ohio by type (fatality, injury, and property damage) during July 2013 to June 2014, and dividing it by the regression estimate provided a percent. This percent was then multiplied by the US regression estimate used earlier. This value is a prediction, based on Ohio, of the impact that the 1 restart per 168 hour restriction and the 1 am to 5 am provision had on truck-safety in the US. The last column, labeled "US regression estimate reduced by 13 percent fatigue accidents", depicts points that are considered what could be achieved if the 13 percent of fatigue related accidents did not occur. In all cases, the Ohio extrapolated point for the US indicates safety was not lower than the US regression point.

Figure 20 HOS Analysis on Property Damage Accidents Involving Trucksillustrates the example of property damage accidents involving trucks discussed in the previous paragraph. This figure highlights the close nature of three of the four estimates: predicted estimate if no HOS change occurred, FMSCA's prediction estimate on the reduction of accidents due to the change of HOS, and the Ohio extrapolated estimate. This is important to note because it shows that the Ohio extrapolated point increased accidents in the US by a marginal amount and not decreased them by the marginal amount predicted. Comparing these three estimates to the possible 13 percent reduction that are currently attributed to fatigue visually shows that this rule was minimally predicted to reduce fatigue related accidents among truck drivers.

Table 17 HOS Analysis

	US Regression Estimate	US Regression Estimate Reduced by FMSCA Prediction (19 Lives, 560 Injuries, 1,400 Property Damage)	Ohio Extrapolated Point on US Acidents Involving Trucks	US Regression Estimate Reduced by 13% Fatigue Accidents
Fatalities Involving Trucks	3249	3230 (-.58%)	3263 (+.43%)	2827 (-13%)
Injuries Involving Trucks	72364	71804 (-.77%)	75826(+4.78%)	62956 (-13%)
Property Damage Involving Trucks	197473	196073 (-.71%)	199873 (+1.21%)	171801 (-13%)

*Data obtained from DoT website for fatalities during years 2002-2012, on June 7, 2014

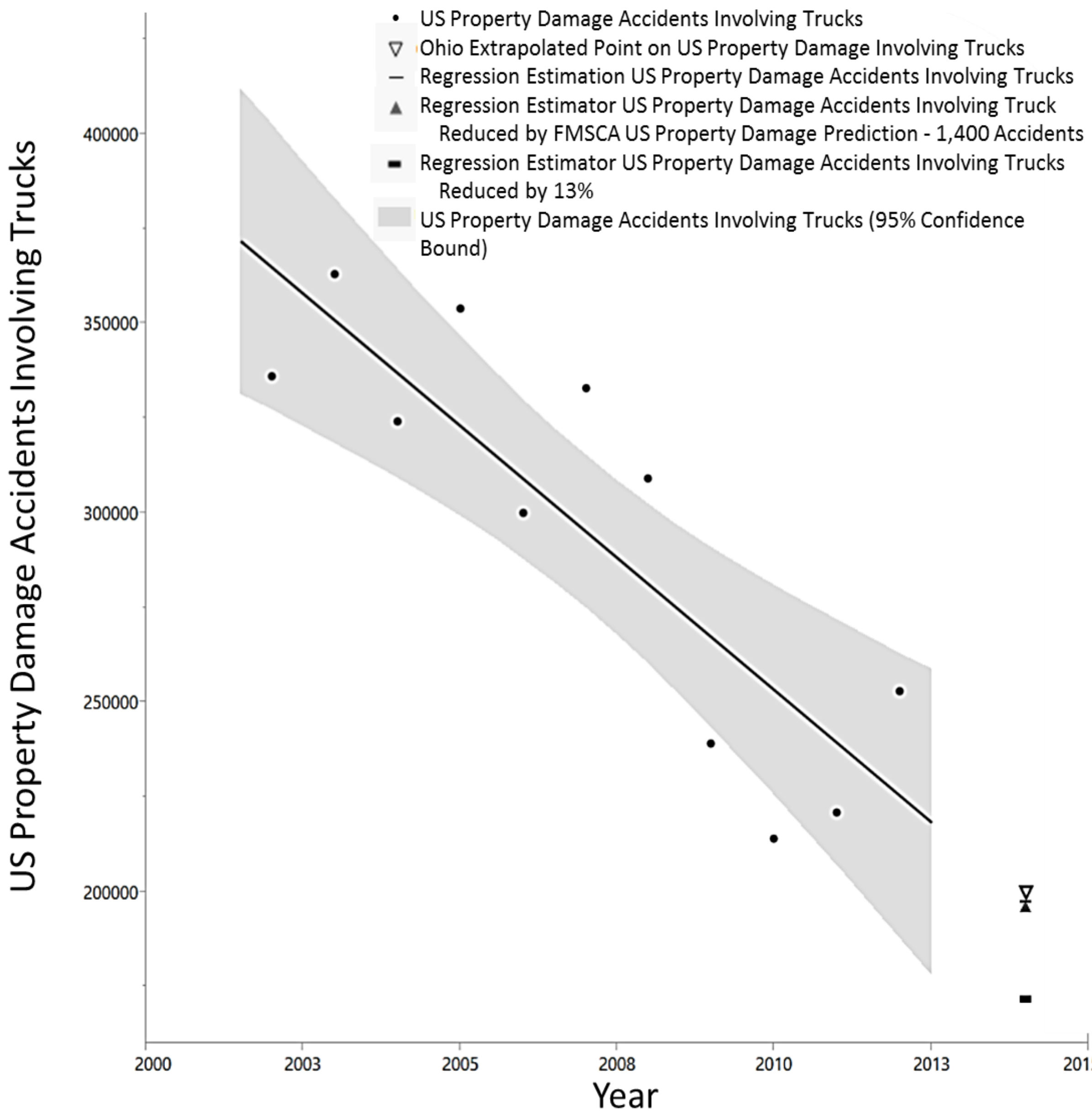


Figure 20 HOS Analysis on Property Damage Accidents Involving Trucks

Table 18 further depicts the magnitude of FMSCA's predictions on reducing fatigue-caused accidents among truck drivers. As previously stated, FMSCA predicted HOS would reduce US truck-related fatalities by 19, injuries by 560, and crashes by 1,400. When compared to the aggregate number of US truck-related accidents, the FMSCA predictions amounts to approximately .5 percent reduction of deaths, injuries, or property damage involving trucks. Utilizing the 13 percent of fatigued-caused accidents and the DoT data from 2012 indicates that truck driver fatigue accounted for 510 fatalities, 13,520 injuries, and 32,890 accidents involving property damage. Reducing these numbers by the predicted FMSCA predictions results in 491 fatalities (a 3.7 percent reduction), 12,960 injuries (a 4.1 percent reduction) and 31,490 (a 4.3 percent reduction).

Table 18 FMSCA's Predicted Fatigue Based on HOS Implementation

Column	A	B	C	D	E	F
	FMSCA (2013) Predicted Change Due to HOS	DOT Data (2012)	% Change	FMSCA (2013) Incidents Caused by Fatigue (13%)	Predicted Reduced Driver Fatigue Incidents	HOS Change on Fatigue
Deaths	19	3921	0.48%	510	12.52%	3.7%
Injuries	560	104000	0.54%	13,520	12.46%	4.1%
Property Damage	1400	253000	0.55%	32,890	12.45%	4.3%
*Formula			=A/B	=13%*B	=D-A	=A/D

Eliminating an Alternative Explanation

To avoid drawing the wrong conclusions about the impact of HOS on driver safety, it is important to demonstrate that changes to the frequency of accidents are not the result of an increase or decrease in vehicles on the road. Although there is no data to show how many vehicles are on all the roads, it is possible to estimate the amount of vehicles driving by comparing the amount of gasoline and diesel gallons taxed and validating the estimate using turnpike traffic. Figure 21 depicts the number of gallons taxed from July 2009 through June 2014 for the state of Ohio. During this period, gas purchases decreased by a mere 0.35 percent while diesel purchases increased by 0.64 percent, and total gallons of fuel purchased increased by only 0.29 percent over the entire 60-month time period. Similarly, vehicles on the turnpike followed consistent yearly patterns during these 60 months, as depicted in Figure 3. The majority of vehicles on the road are class 1 (low two-axle) followed by class 5 (high

5-axle). The peaks (summer) and lows (winter) are the changes in traffic flow that occurs throughout the calendar year.

When combined, these two classes of vehicles account for 94.5 percent of all vehicles. Over the 60-month time period, vehicle traffic on the Ohio Turnpike changed by the following amounts: 0.01 percent decrease in class 1, 0.05 percent increase in class 5, and 0.03 percent increase in all classes. The Ohio Turnpike data reveals that all classes of traffic changed by a rate corresponding with fuel taxes. Both figures have highs and lows that indicate the seasonality of driving, which is captured in the analysis by ensuring the same months (July-June) of the given year remains constant.

Since both figures show that there were only negligible changes to vehicle traffic between the various 12-month periods and the use of fuel in Ohio, overall changes in traffic were ruled out as a potential cause of the changes in truck-related accidents and no adjustments were made to account for them as part of the analysis.

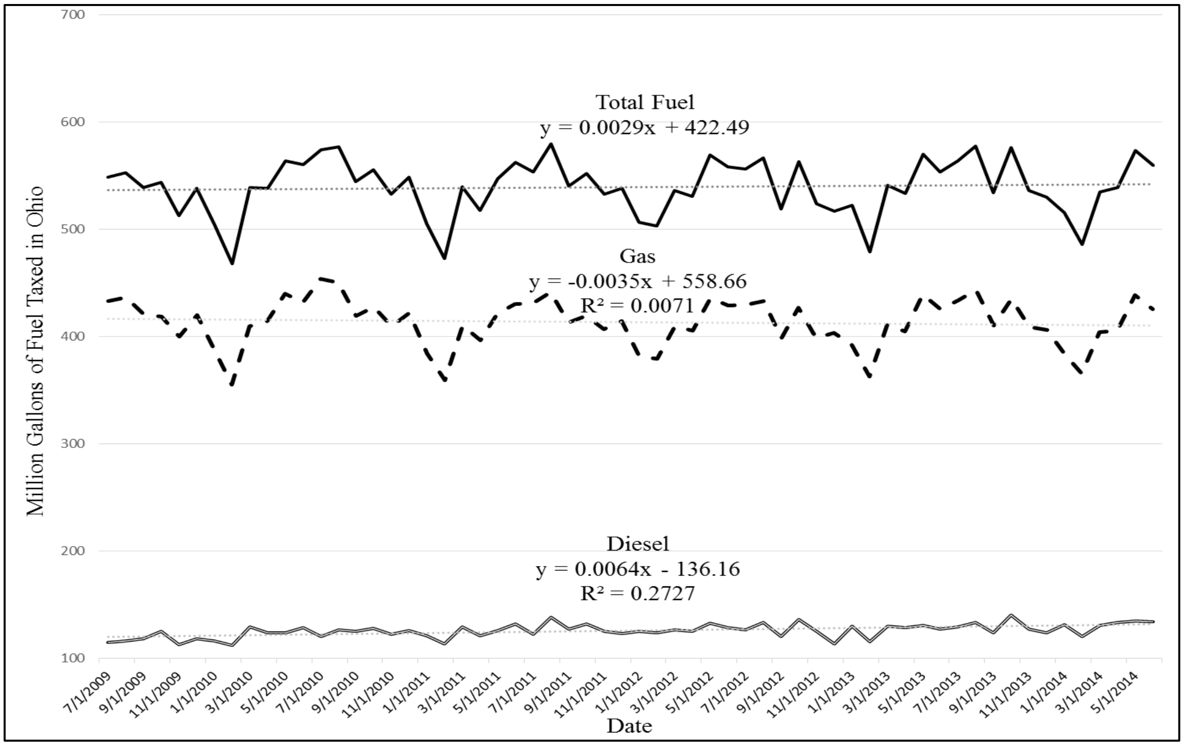


Figure 21 Ohio Million Fuel Gallons Taxed 2009-2014

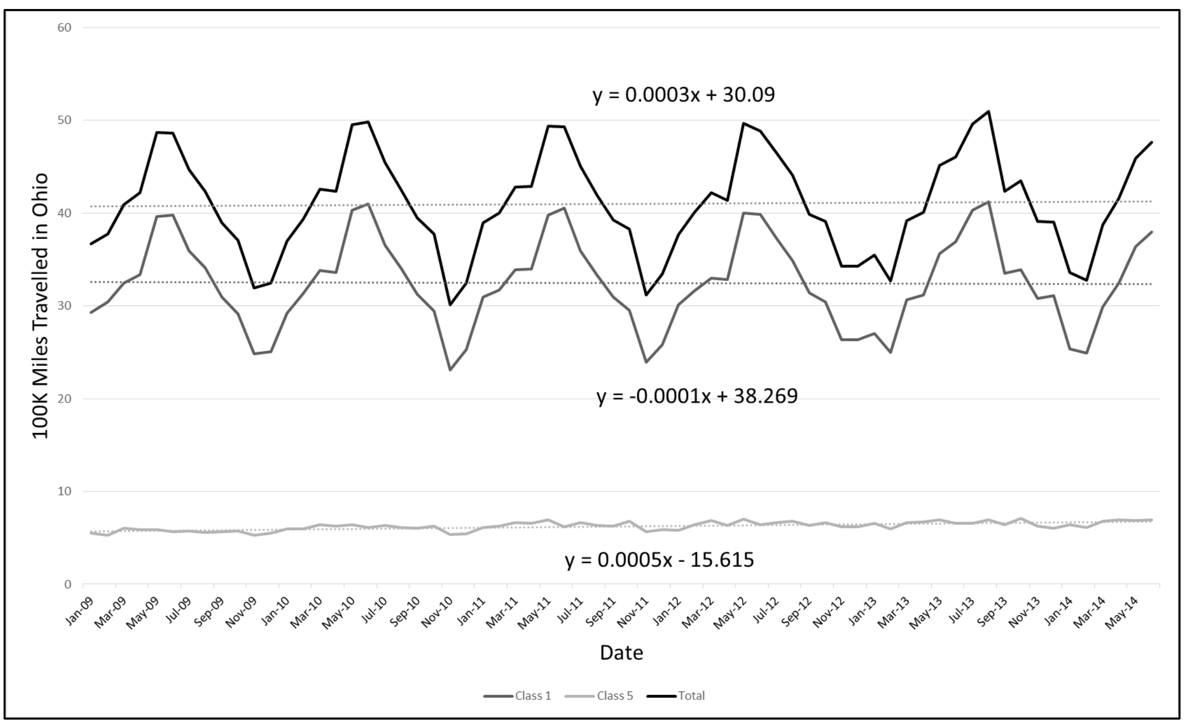


Figure 22 Vehicles on Ohio Turnpike 2009-2014

Discussion

Comparing the accidents involving truck drivers prior to the 1 restart per 168 hour restriction and the 1 am to 5 am provision to the accidents after the HOS changes indicated a significant difference for both injuries and property damage. This analysis showed that pre-HOS injuries caused by or involving truck drivers (both <.001) and property damage caused by or involving truck drivers (<.001 and .007 respectively) were significantly lower than post HOS accidents of the same type (See Table 10 and Table 11). However, the difference in fatalities caused by (p = .589) or involving truck drivers (p-value = .309) were not significant. At first glance, it is possible to think that the HOS change significantly reduced the accidents involving truck drivers. However, the significance does not appear to be the result of the HOS change but rather the steady downward trend of accidents that is continually occurring.

The trend of accidents involving trucks, as annotated in the literature review, has been on a continuous decline. This decline is also revealed in the test results shown in Table 13 and Table 14. These tables generally indicated that the reference year is most similar to the most recent contrasted year. For example, in Table 13, the Least Square Difference (LSD) between July 2013-June 2014 and the 2012-2013 year had a mean difference of -10.92 (p-value =.518) for injuries involving trucks and a -3.080 (p-value=.744) for injuries caused by trucks. As the contrasted year becomes further away with respect to time the mean difference tends to grown and the p-values become significant: indicating a downward trend for this type of accident.

Comparing the pre- and the post- HOS data significant differences were found, possibly implying that the HOS changes reduced accidents involving truck drivers.

However, the general decreasing trend of the number of accidents involving trucks were driving the differences and not the HOS regulatory changes. In order to more accurately account for this general downward trend, the percentage of accidents caused by truck drivers were analyzed, and the pre-HOS group was divided into four separate years and reanalyzed.

The percent of accidents caused by truck drivers are very different than the number of accidents caused or involving trucks. The percentage of accidents caused by truck drivers should theoretically change when new safety technologies, improvements in training, or beneficial regulations emerge, which only effects truck drivers. Although not significant, this research found that the percent of truck drivers at fault increased in all three categories: fatal from 28.28 percent to 36.72 percent (p-value=.114), injury 52.04 percent to 54.46 percent (p-value=.113), and property damage from 58.63 percent to 60.92 percent (p-value=.247). This percentage increase of truck drivers at fault suggests that the HOS revision was not beneficial to the safety of truck drivers and motorists on roads with truck drivers.

Separating the pre-HOS into four separate years on the number of accidents involving and caused by truck drivers indicated no significance difference between the year the 1 restart per 168 hour restriction and the 1 am to 5 am provision was in place to the previous year (see Table 13Table 14). This suggests that the number of accidents were neither increased nor decreased to a significant level due to the HOS change.

Upon further testing the percent of truck drivers at fault for fatalities, injuries, and property damage accidents by separating the pre-HOS into four years yielded interesting results. First, there was a significant difference (increase) in the percent of truck drivers causing fatalities during the 1 restart per 168 hours restriction and 1 am to 5 am provision from the previous year not under this regulation (p-value=.026 see Table 16). Although this same percent was higher than the other contrasted years, it was not at a significant level. The percent of injuries and property damage caused by truck drivers was also at its highest during the 1 restart per 168 hours and 1 am to 5 am HOS regulation period, but it was not at a significant level (with p-values ranging from .069 to .681 see Table 16).

Extrapolating the HOS impact on accidents involving trucks from Ohio to the US revealed that the accidents for fatalities, injuries, and property damage all were above the regressed estimate for that time period (see Table 17). This suggests that HOS may not have reduced fatigue related accidents as FMSCA projected.

This research is unable to determine if the HOS change resulted in the reduction of 19 fatalities, 560 injuries, and 1,400 property damage accidents involving trucks. This is in large part due to the very small percentage of accidents that occur annually in the US involving trucks. As demonstrated in the analysis, 13 percent of accidents involving truck drivers have been attributed to fatigue. This 13 percent translates to 510 fatalities, 13,520 injuries, and 32,890 property damage accidents in the US for 2012 (see Table 18). FMSCA predicted that HOS would reduce by 4 percent the number of accidents caused by fatigued truck drivers and reduce by approximately .5 percent the number of total accidents involving trucks (see Table 18). Although these reductions are not inconsequential, HOS does not address the other 96 percent of accidents caused by fatigued truck drivers. Given the cost and challenges of implementing HOS, addressing only 4 percent is problematic and further research is needed to provide greater results in the reduction of truck driver accidents due to fatigue.

Conclusions and Implications

There are many important managerial findings from this research: 1) significant differences exist between pre- and post-HOS regarding the number of injuries, and property damage accidents involved and caused by truck drivers but not for fatalities, 2) recent HOS changes (1 restart per 168-hours restriction and 1 am to 5 am provision) did not significantly change the continuing downward trend of accidents involving trucks, 3) when analyzed using 12-month periods, post-HOS number of accidents involving or caused by truck drivers is not significantly different than the prior 12 months in any category, 4) percent of accidents caused by truck drivers from July 2013 to June 2014 increased for fatalities, injuries and property damage accidents (p-values between 0.113 and 0.247), suggesting that the HOS changes (1 restart per 168 hours restriction and the 1 am to 5 am provision) made truck drivers more likely to be at fault for the accident than the period of July 2009 to June 2013, which was prior to the change; also, the percent of fatalities caused by truck drivers was significantly higher (p-value = .026) than the previous year, which was not regulated by the 1 restart per 168 hour restriction and the 1 am to 5 am provision, and 5) the regression analysis and point estimates show that the US fatalities for the period of July 2013 to June of 2014 (1 restart per 168 hour restriction and the 1 am to 5 am provision) are slightly above the trend line of accidents in the US. Additionally, this research brings to light the small predicted impact that FMSCA claims HOS will have on fatigued truck drivers; showing that this regulation change in HOS was predicted to reduce all accidents involving trucks by less than 1 percent, and fatigue-caused accidents by approximately 4 percent.

Countering fatigue is a difficult, if not impossible, feat for legislators. A “one-size” fits all approach of HOS will have numerous direct and indirect negative safety effects that are difficult to predict. This research has shown that HOS has not decreased the percentage of accidents caused by truck drivers in the state of Ohio. Furthermore, the rate at which accidents had previously been decreasing due to other factors did not significantly change because of the restart restrictions introduced into HOS.

Enacting new HOS regulations came at a great expense to the individuals, the industry, and ultimately the consumer. In fact, Short (2013) found that 66.3 percent of truck drivers surveyed were more fatigued and 27.8 percent were much more fatigued due to the updated HOS restart restrictions. Not only were truck drivers reporting that they were more fatigued, but daytime traffic congestion has also increased due to HOS requirements, making roads less safe (Montague 2014; Short & Murray 2014; Downs 1992; Chen et al. 2015)

Better enforcement of other regulations may be a more effective and cheaper alternative to HOS implementation. For example Craft and Blower (2004) demonstrated that 29 percent of accidents caused by trucks were the result of brake problems on trucks and that fatigue ranked seventh in terms of risk importance. Improved trucking compliance on brake safety could have more than double the impact of attempting to counter fatigue. The bottom line, is when legislation is passed that has questionable effects, more research should be accomplished prior to its implementation.

Accidents are a terrible tragedy. There are many reasons why accidents occur. Government HOS regulations need to be well researched prior to implementation. With respect to the 1 restart per 168 hours restriction and 1 am to 5 am provision, thorough research was not completed until 1 year after the enactment of the rule (Ferro 2014). The eventual suspension of these provisions indicates the very real possibility of some unintended consequences this HOS regulation may have had on truck drivers and motorists. This research has shown that truck drivers within Ohio are not causing a smaller percentage of fatalities, injuries, or property damage, the exact opposite of the intent of HOS.

Future Research

The data from Ohio is only a sample. Once data is available at the national level, it too should be explored to better understand the HOS effects on truck driver and overall motorist's safety. Additional analysis should be conducted on other possible causal factors that affect safety that may not be tracked or apparent at this time. For example, high driver turnover may have resulted from the HOS regulation, and high driver turnover has been shown to increase accidents due to a decrease in route familiarity and schedule (Staplin & Gish 2005; Griffin et al. 1992)

Further studies should examine how other career fields are mitigating fatigue and reducing accidents. For example, the medical field has made numerous improvements to handle fatigue (i.e., ER doctor and staff shifts), while the airline industry has reduced pilot fatigue. The effort of these industries has a lot to offer the trucking industry through benchmarking.

Further research is needed on countering fatigue among truck drivers. Rather than dealing with actual numbers of accidents, research focusing on percentages will yield fewer confounding results by ruling out changes driven by market force innovations that equally affect truck drivers and other motorists. Additional research can also be conducted by expanding the timeframe to the entire period that the 1 restart per 168 hours and 1 am to 5 am provision was in place, providing greater numbers and clarity to its impact on truck drivers' safety.

VI. Conclusions and Recommendations

This chapter presents the main findings from this research. Implications and recommendations are then provided based on the conclusions of this research. This section will also address specific implications to the Air Force.

Research Conclusions and Air Force Implications

The first research objective was to discover if HOS regulation was different from the other safety regulations examined. A typology construct was created to classify these regulations and to examine the differences in the types of regulations. HOS regulation was found to be the only safety regulation studies as the objective-indirect type. No regulations studied moved from direct to indirect or indirect to direct, but since the majority of regulations are classified as direct it would seem that this type of regulation is preferred. Since HOS is regulating a factor related to fatigue but not fatigue itself, it makes more sense why this regulation is continually changed. This regulation substantially changed on average every 7.09 years. This was statistically more frequent than changes to subjective-direct (p value .003) policy type. In the event that a technology came out that could measure driver-fatigue, hours of service regulation may become direct. Until that time, it is very likely that more HOS regulatory reform will continue in an attempt to indirectly regulate fatigue.

The other regulations that were examined primarily started as subjective-direct and ended as objective-direct. If a change occurred, subjective-direct regulation types moved to objective-direct 28.5 percent of the time, and only moved back 3 percent of the time (due to a unique situation); leading to 7 of the 11 initially subjective-direct *type* ending as an objective-direct *type*. This implies that objective regulations seem to be preferred to subjective regulations.

This typology was also empirically tested and significant differences were found among the various types. Subjective-direct regulations types (19.67 years) changed significantly less frequently than objective-direct types (13.67 years) and objective-indirect *types* (7.09 years). There was also a statistical difference among the size (characters, and sections) of the different types of regulation. Of the three types classified in this research, all were significantly different (p-value $<.0001$). Subjective regulations were the smallest, which could be explained by lack of regulation needed to describe intent rather than enforceable procedures. The objective-indirect type was substantially larger than either objective-direct or subjective-direct types. Since there are many indirect factors that contribute to the problem, indirect regulations may naturally grow in size to attempt to control these many factors.

The implications of the second chapter are far-reaching due to the practical typology created. Managers, legislators, and government agencies can benefit from understanding the different classifications while creating or modifying rules and regulations. Creating only subjective rules may most likely lead to less control and ambiguous policies, while creating objective regulations may lead to greater control and clearer policies. Indirect policies may lead to more changes over time and more complex regulations. In creating rules and regulation it would appear that some initial subjectivity is needed to provide the intent and goal, while the majority of the regulation should seek to be objective to provide more legal clarity and to utilize emerging technologies.

This understanding of regulation types would benefit the Air Force and the entire DoD. When writing or reviewing Air Force Instructions (AFIs), it is important to consider the instruction type. If the instruction is direct or indirect and objective or subjective it will have varying levels of impact on Airmen. Indirect instructions may most likely not solve the problem and may create unforeseen or unsafe situations. This may occur since the AFI is attempting to control only an associated factor of the problem, leaving other factors with no instruction. Direct instructions provide the safety needed for all Airmen, especially those who are less experienced and need guidelines in order to ensure their safety. As previously stated, when a direct type of instruction is followed it provides guidance that leads to safer operations. However, AFIs should also include some subjectivity. This provides the overall goal of the instruction, which is beneficial when situations arise that are unique that are not specifically covered in the AFIs. However, the majority of the instruction should be objective regulations that can be easily followed. This will not only provide the overall goal but also the parameters necessary to ensure mission accomplishment and safety.

The third chapter moved to further expand the knowledge with respect to the incentives provided to truck drivers through the lens of perishable inventory theory and its associated tactics. The applied tactics in this research were capacity, flexibility, substitution and or elimination, FIFO or LIFO, heterogeneity, and planning. This research found great capacity differences in the various HOS regulations based on the exhaustive enumeration method, which may result in less safety due to future investments and planning in the truck driving industry. This research also found that restrictions limit the flexibility of truck drivers, which has unintended consequences such as increased congestion, or avoiding resting when tired; both of which have major safety implications. Additionally, this research showed how capacity could be increased through daily and weekly schedule changes, which, based upon the heterogeneity capability of the truck driver, may have negative safety implications. Further complicating these tactics of perishability are the frequent HOS changes, which further destabilize the industry. Analyzing HOS through the exhaustive enumeration technique and viewing the HOS regulatory constantly changing regulations through the lens of perishable inventory theory, HOS regulations have some major negative safety implications to truck drivers currently and to the truck driving industry in the future. Future unintended consequences can be avoided by following this researches approach and method prior to implementation of future regulations.

The Air Force may be able to manage Airmen based on the tactics of perishable inventory theory. For example, the Air Force attempts to manage fatigue like FMSCA by limiting the hours a pilot can be on duty. There are 24-hour period, 7-day period, 30-day period, and 90-day period restrictions on the amount of hours a pilot can operate. Different types of aircrafts have different rules (single seat versus crew aircraft). For example, pilots in two different crew aircraft (C-130 and the KC-135) experience the same flight hour restrictions, but very different fatigue levels. The KC-135 refueled other aircraft, making the mission much less stressful because it entailed a takeoff, orbit, multiple refueling, and a landing. Although there may be eight flight hours (the value used in the 24-, 7-, 30-, and 90-day restrictions) accumulated in a 12-hour duty day, it was not as fatiguing as the C-130 mission. In a C-130 mission, there were multiple combat takeoffs (wearing of helmets and protective armor), combat landings, unloadings, reconfigurations, and reloadings. In a similar 12-hour duty day a pilot may only achieve 5 hours of flying. Since the limitations are based on flight time, it would appear that the pilots of the KC-135 would be much more fatigued than the pilots of the C-130. However, this is not the experience of many pilots. Fatigue is much more complicated than just the flight hours recorded. McClelland's research (2013) also drew the same conclusion, which he found that flight time is not the right approach to understanding fatigue.

Reevaluating how the Air Force manages people with respect to fatigue is a complicated and incredibly important issue. Given that Airmen operate expensive equipment, performing risky operations, and can have large impacts on international relations; it is critical that they are not fatigued while performing these duties. This research has shown that indirect measures, such as flight-time, can lead to operators being in compliance, but still failing by being fatigued.

The fourth chapter researched the safety efficacy of the recent HOS change. The research in this chapter found: 1) Significant differences exist between pre- and post-HOS regarding the number of injuries, and property damage accidents involved and caused by truck drivers but not for fatalities, 2) Recent HOS changes (1 restart per 168-hours restriction and 1 am to 5 am provision) did not significantly change the continuing downward trend of accidents involving trucks, 3) When analyzed using 12-month periods, post-HOS number of accidents involving or caused by truck drivers is not significantly different than the prior 12 months in any category, 4) Percent of accidents caused by truck drivers from July 2013 to June 2014 increased for fatalities, injuries and property damage accidents (p-values between 0.113 and 0.247), suggesting that the HOS changes (1 restart per 168 hours restriction and the 1 am to 5 am provision) made truck drivers more likely to be at fault for the accident than the period of July 2009 to June 2013, which was prior to the change; also, the percent of fatalities caused by truck drivers was significantly higher (p-value = .026) than the previous year, which was not regulated by the 1 restart per 168 hour restriction and the 1 am to 5 am provision, 5) The regression analysis and point estimates show that the US fatalities for the period of July 2013 to June of 2014 (1 restart per 168 hour restriction and the 1 am to 5 am provision) are slightly above the trend line of accidents in the US. Additionally, this research highlighted the small predicted impact that FMSCA claims HOS will have on fatigued truck drivers; showing that this regulation change in HOS was predicted to reduce all accidents involving trucks by less than 1 percent, and fatigue-caused accidents by approximately 4 percent.

The Air Force could gain insight from this research by conducting similar types of analysis on safety outcomes in aircraft when the AFIs change or when there are waivers. For example, the Air Force waived the 30-day flight-time to allow more flight hours during Operation Iraqi and Operation Enduring Freedom. The safety results before and after this waiver was implemented, would provide information to the Air Force regarding this flight duty period restriction as well as the sensitivity to changing these hours and associated safety implications. Variables such as mishaps (class a-d), and in-flight emergencies should be analyzed before and after the flight-time waiver was established. Additional research should examine the safety differences between aircrafts and jobs based on factors that are related to fatigue, which may not be addressed in the AFIs.

Summary

The Air Force relies on the truck industry to deliver the logistical capabilities to ports, airfields, and rail-stations in order to deliver the needed resources to those in combat. Restricting the capability of truck drivers will also restrict the capability of delivering this logistical capability to our Airmen in combat. Furthermore, the Air Force is dependent on funding that is generated by the economy, which is largely reliant on the fiscal health of the trucking industry. Therefore, a weak truck industry will have negative impacts to the economy, which means a weaker Air Force.

Countering fatigue indirectly is a difficult, if not impossible, feat for legislators. Attempting to regulate fatigue indirectly will lead to a continually changing regulatory environment that will have consequences on the trucking industry, the supply chain, and the economy. The trucking industry will continually adjust the number of drivers and associated support structure in order to provide a certain service level. These changes may have negative safety implications and the supply chain will have to adapt to changing delivery times and number of warehouses. The economy, given that 1 in 15 people work in the trucking industry (All Trucking 2016), will be impacted by these regulatory changes, which is why it is critical to get it right.

This research provides more insight on how to get HOS regulation to offer more safety to truck drivers and motorists. It is important that this regulation is directly measuring its intended goal—fatigue. Moreover, by measuring fatigue instead of hours of operation, the many different unintended consequences (safety and economically), which this research found, may be avoided.

Future Research

Given the new regulation typology proposed by this research, there is a plethora of future research needed to either further substantiate it or find its weaknesses in different fields. Additional research can be conducted on different characteristics of the *types* discussed in this research. Some of these include the efficacy of the regulation or rule to see which regulations tend to provide better results regarding their intended objective. Other characteristics such as cost could be explored in order to provide a better cost-benefit of different regulation *types*.

Truck drivers could and should be asked directly about these perishability concepts and tactics in future research. Surveys analyzing truck companies and drivers, pre and post HOS changes, with respect to the concepts of perishable inventory theory could establish greater credibility for the theoretical foundation presented in this research. Such research would provide greater insight into and evidence of the actual safety implications of the current regulatory environment.

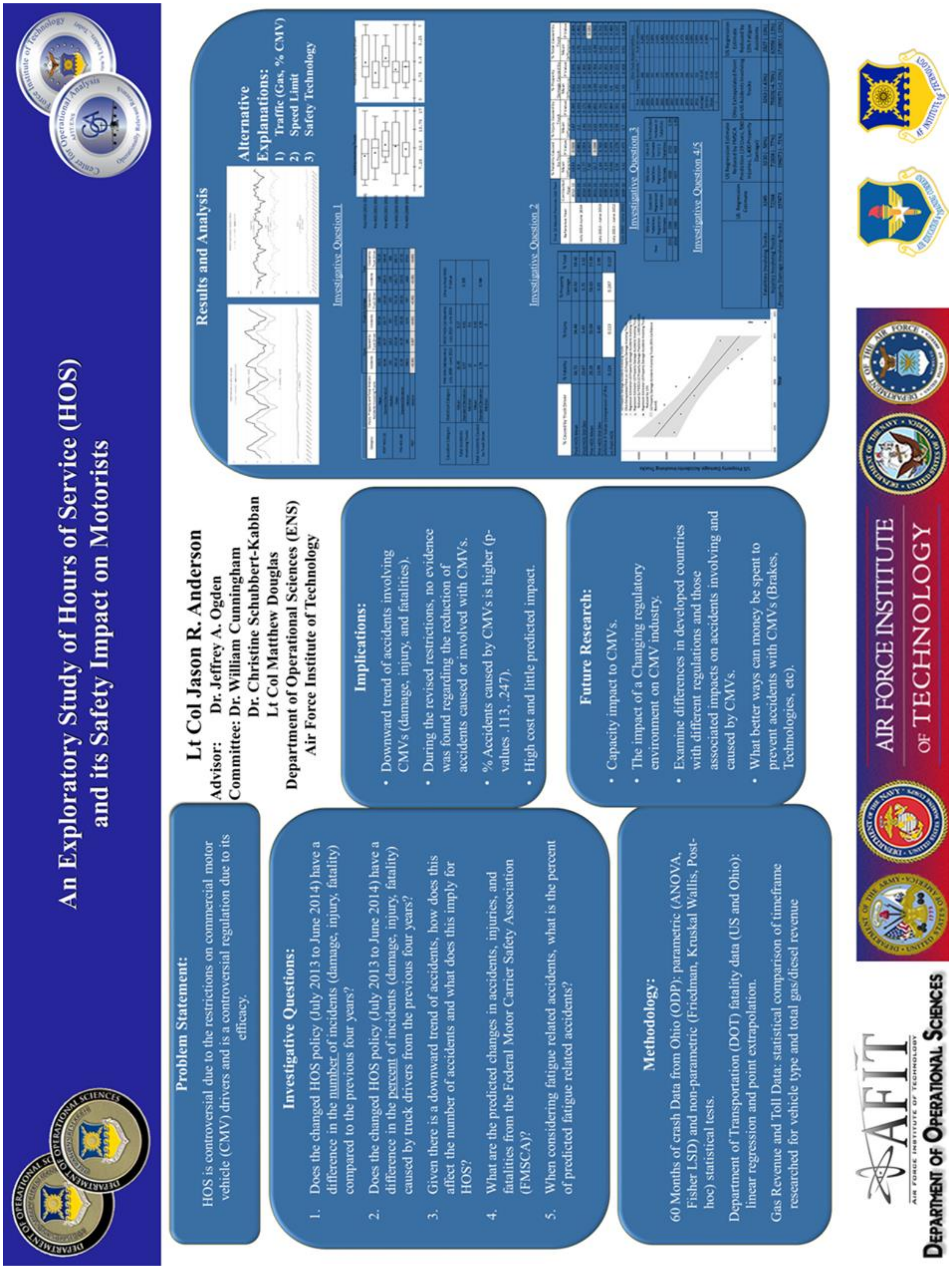
Additional research is needed in coalescing regulators and truck industry experts with respect to safety as part of the field of managerial controls (Miller & Saldanha 2013) and in order to ensure wiser regulatory policies (Breyer 1986). Moreover, future research should look at directly measuring driver fatigue, through technologies such as the "sleepalyzer" (Williams et al. 2012, p.120), so that those direct measurements can be used to develop direct regulations, instead of indirect regulations that hope fatigued driving does not occur.

The data from Ohio is only a sample. Once data is available at the national level, it too should be explored to better understand the HOS effects on truck driver and overall motorist's safety. Additional analysis should be conducted on other possible causal factors that affect safety that may not be tracked or apparent at this time. For example, high driver turnover may have resulted from the HOS regulation, and high driver turnover has been shown to increase accidents due to a decrease in route familiarity and schedule (Staplin & Gish 2005; Griffin et al. 1992)

Further studies should examine how other career fields are mitigating fatigue and reducing accidents. For example, the medical field has made numerous improvements to handle fatigue (i.e., ER doctor and staff shifts), while the airline industry has reduced pilot fatigue. The effort of these industries has a lot to offer the trucking industry through benchmarking.

Further research is needed on countering fatigue among truck drivers. Rather than dealing with actual numbers of accidents, research focusing on percentages will yield fewer confounding results by ruling out changes driven by market force innovations that equally affect truck drivers and other motorists. Additional research can also be conducted by expanding the timeframe to the entire period that the 1 restart per 168 hours and 1 am to 5 am provision was in place, providing greater numbers and clarity to its impact on truck drivers' safety.

Appendix A. Storyboards



Evaluating Hours of Service Impact on Truck Driving Capacity and Safety Implications: An Application of Perishable Inventory Theory

Problem Statement:

HOS is controversial due to the restrictions on commercial motor vehicle (CMV) drivers and is a controversial regulation due to its efficacy.

Investigative Questions:

1. Is this an uncertain regulatory period, and if so, what is the impact to the truck driving industry?
2. How do the different HOS rules that were recently changed impact the capacity in the truck driving industry?
3. What are the possible safety implications of an uncertain and capacity changing regulatory environment?
4. How do the concepts of perishable inventory theory help provide explanations for business actions in the trucking industry?

Methodology:

Exhaustive Enumeration utilizing the different daily, weekly, and restart constraints.

Matlab8.4L Simulation validating the EE technique and a useful tool for TL and LTL drivers.

Implications:

- Inventory perishable theory expanding the understanding of how truck driver service can be viewed.
  - Long Term Plan, Capacity, Flexibility, FIFO LIFO, Heterogeneous
- Large capacity change compounded with frequent regulatory change leads to an uncertain business environment for the trucking industry.
- Uncertain regulatory environment and postponement of investments for both equipment and personnel.

Lt Col Jason R. Anderson

Advisor: Dr. Jeffrey A. Ogden

Committee: Dr. William Cunningham

Dr. Christine Schubbert-Kabban

Lt Col Matthew Douglas

Department of Operational Sciences (ENS)

Air Force Institute of Technology

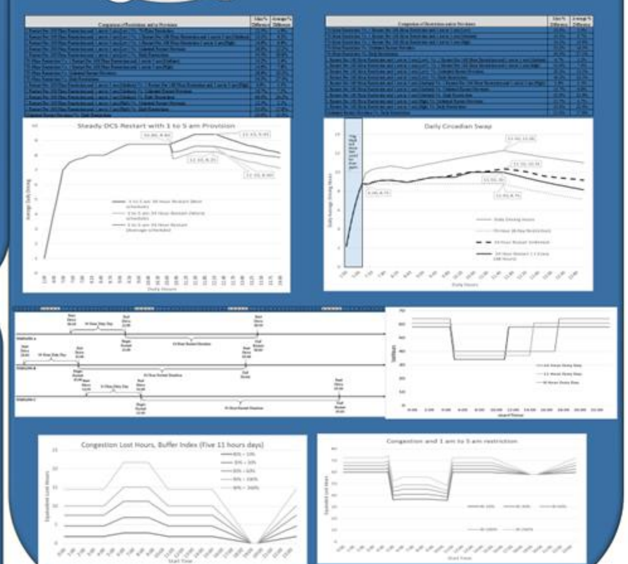
HOS Restrictions and Provisions

Year Changed	1938	1939	1962	2003	2005	2013	2014
Driving Hours	12	10	10	11	11	11	11
On-Duty Hours	15	N/A	N/A	14	14	14	14
Max Daily Work	12	N/A	N/A	N/A	N/A	N/A	N/A
Off-Duty Hours	9	8	8	10	10	10	10
Duty Cycle	24	24	N/A	N/A	N/A	N/A	N/A
60 Hour (7-day)	60	60	60	60	60	60	60
70 Hour (8-day)	70	70	70	70	70	70	70
Break						≥8	≥8
Restart				≥34	≥34	≥34	≥34
Number of Restarts						1 Per 168 Hrs	N/A
1 am to 5 am						≥2	N/A
Sleeper Berths Split Sleep				≥2 hrs	≥8 hrs	≥8 hrs	≥8 hrs
Changes	7	4	1	5	1	3	2

Future Research:

- Surveys of businesses on postponement decisions for equipment or personnel.
- The impact of a Changing regulatory environment on CMV industry.
- Examine differences in developed countries with different regulations and those associated impacts on accidents involving and caused by CMVs.
- What better ways can money be spent to prevent accidents with CMVs (Brakes, Technologies, etc).

Results and Analysis



AIR FORCE INSTITUTE OF TECHNOLOGY

AFIT Air Force Institute of Technology

Department of Operational Sciences

A Typology Classification Approach to Exploring Differences in Commercial Motor Vehicle Safety Regulations

Lt Col Jason R. Anderson
Advisor: Dr. Jeffrey A. Ogden
Committee: Dr. William Cunningham
Dr. Christine Schubert-Kabban
Lt Col Matthew Douglas
Department of Operational Sciences (ENS)
Air Force Institute of Technology

Problem Statement:

Regulations change and impact the industry in which they govern, predicting when and how regulations will change provides a great benefit to business.

Investigative Questions:

1. What are the triggers that make a regulation get revised to move into a different quadrant ?
2. When regulations are in a particular quadrant, what direction and how long does it take till they move into a different quadrant?
3. Can the types of regulation be empirically differentiated based on character count, section count, the number of changes, and time to change?

Methodology:

Categorical analysis on HOS regulations. Track 14 different policies with respect to the regulation evolution model. Classify initial regulation and all subsequent changes. Empirically test the different types through statistical parametric and non-parametric means.

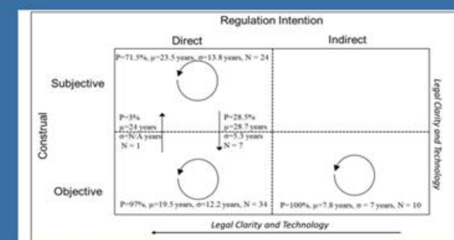
Implications:

- Categorical tool to better understand policy based on four quadrants: Subjective-Direct, Subjective-Indirect, Objective-Direct, and Objective-Indirect.
- Understanding of why policy is revised
- Prescriptive tool for businesses and researches on how, how often and why policy changes.
- Theoretical development regarding types of regulation.

Code of Federal Regulations Examined

1. Commercial Driver's License (CDL) Requirements
   A. Driving record (10 years) (disqualification from different state)
   B. Knowledge and skills tests
   C. Medical Tests
2. Mx (Tires and brakes)
3. HOS (Inspection logs)
4. Age requirements (
5. Impairment (Drugs, and drinking)
   A. Drugs
   B. Drinking .04% BAC now
6. Distracted driving (Phone, reaching or out of position)
   A. Phone
   B. GPS
   C. Food
   D. Any distraction
7. Pre-check of vehicle and sign-off log
8. Hazardous material handling
9. Trailer requirements (hitch height, tape along trailer, warning signs, DOT number, height of vehicle etc) http://www.txdps.state.tx.us/cve/markings.htm
10. Weight total of truck
11. Inspections (CSRs)
    A. Company records
12. Load checking requirements (3 hr 150 mile
13. Noise Emissions (Part 325)
14. Exhaust Systems (Part 325 g)

Results and Analysis



Date	1938	1940	1950	1960	1970	1980	1990	2000	2010	2016
CFR	1	3	15	25	35	45	55	65	75	81
Brake Performance	63%/100% (3,853)	75%/100% (3,1199)	75%/100% (3,1223)	63%/100% (3,971)	100%/100% (6,954)	100%/100% (10,1617)	100%/100% (10,1617)	100%/100% (10,1617)	100%/100% (11,2240)	100%/100% (11,2240)
Sleeper Berth	–	–	–	70%/78% (12,3852)	70%/78% (12,3983)	62%/78% (20,3716)	62%/78% (21,3571)	62%/78% (21,3571)	62%/78% (21,3571)	62%/78% (21,3570)
Equipment Inspection	–	%/100% (2,206)	%/100% (2,206)	71%/79% (6,1414)	71%/79% (7,1447)	77%/91% (12,1909)	77%/86% (11,1737)	77%/82% (10,1776)	75%/84% (10,2003)	75%/84% (10,2003)
Tires	25%/75% (2,199)	25%/75% (2,207)	25%/75% (2,207)	33%/100% (4,919)	100%/100% (6,915)	92%/98% (14,2494)	93%/93% (16,3016)	94%/94% (17,1821)	93%/94% (18,3191)	93%/94% (18,3191)
Cargo Inspection	0%/100% (2,199)	0%/100% (2,207)	0%/100% (2,207)	0%/100% (4,919)	17%/100% (6,915)	48%/98% (14,2494)	48%/98% (16,3016)	48%/98% (17,1821)	48%/98% (18,3191)	48%/98% (18,3191)
Hazardous Conditions	0%/100% (2,298)	0%/100% (2,326)	0%/100% (2,326)	0%/100% (2,326)	0%/100% (2,668)	0%/100% (2,668)	0%/100% (2,668)	0%/100% (2,725)	0%/100% (2,725)	0%/100% (2,728)
Impaired Driving	0%/100% (2,461)	0%/100% (2,474)	0%/100% (2,465)	0%/100% (2,465)	0%/100% (2,459)	0%/100% (2,643)	0%/100% (2,643)	0%/100% (2,708)	0%/100% (2,708)	0%/100% (2,709)
Knowledge	0%/75% (2,358)	0%/75% (2,334)	0%/75% (2,335)	0%/75% (2,335)	0%/100% (2,187)	89%/100% (12,3616)	89%/100% (12,3616)	0%/100% (2,187)	0%/100% (2,187)	0%/100% (2,187)
Experience	13%/100% (3,303)	13%/100% (3,329)	13%/100% (2,324)	13%/100% (2,324)	13%/100% (4,368)	76%/93% (20,2386)	76%/93% (20,2386)	76%/93% (20,3522)	76%/93% (20,3523)	76%/93% (20,3516)
Narcotics	25%/75% (2,79)	25%/75% (2,166)	25%/75% (2,159)	25%/75% (2,159)	25%/75% (2,159)	68%/100% (8,990)	75%/100% (9,1024)	75%/100% (9,1045)	75%/100% (9,1045)	75%/100% (9,1045)
Alcohol	25%/100% (2,186)	25%/100% (2,247)	25%/100% (2,247)	25%/100% (2,247)	25%/100% (2,348)	85%/95% (8,1009)	84%/93% (15,2580)	90%/94% (17,2717)	90%/94% (17,2723)	90%/94% (17,2735)
Hearing	0%/100% (2,35)	0%/100% (2,35)	0%/100% (2,35)	0%/100% (2,35)	75%/100% (2,122)	75%/100% (2,434)	75%/100% (2,434)	75%/100% (2,434)	75%/100% (2,434)	75%/100% (2,434)
Eyesight	0%/100% (1,151)	100%/100% (1,292)	100%/100% (1,292)	100%/100% (1,292)	100%/100% (1,375)	100%/100% (1,470)	100%/100% (1,470)	100%/100% (1,470)	100%/100% (1,470)	100%/100% (1,470)
HOS	100%/0% (4,1185)	100%/0% (4,1363)	100%/0% (3,2596)	100%/0% (3,2596)	100%/0% (6,3264)	100%/0% (8,3424)	100%/0% (16,2622)	100%/0% (8,1220)	100%/0% (7,1117)	100%/0% (15,2736)

	Objective Direct (OD)			Subjective Direct (SD)			Objective Indirect (OI)			Comparison
	μ	σ	n	μ	σ	n	μ	σ	n	(P-Value)
Character Count	1866.7	1235.6	553	637.5	623.7	439	2432.0	826.0	79	OI>OD>SD (<.0001)
Section Count	9.9	6.6	553	3.5	3.5	439	7.25	3.7	79	OD>OI>SD (<.0001)
Years Until Substantial Change	14.4	15.3	43	19.5	13.7	25	7.8	7.0	11	SD>OD (.017), SD>OI (.003)

AIR FORCE INSTITUTE OF TECHNOLOGY

AFIT AIR FORCE INSTITUTE OF TECHNOLOGY DEPARTMENT OF OPERATIONAL SCIENCES

Bibliography

Aarts, L. & Van Schagen, I., 2006. Driving speed and the risk of road crashes: A review. *Accident Analysis & Prevention*, 38(2), pp.215–224.

Abouk, R. & Adams, S., 2013. Texting bans and fatal accidents on roadways: Do they work? Or do drivers just react to announcements of bans? *American Economic Journal: Applied Economics*, 5(2), pp.179–199.

Abrams, C., Schultz, T. & Wylie, C., 1997. Commercial Motor Vehicles Driver Fatigue, Alertness, and Countermeasures Survey. *The National Academies of Sciences Engineering Medicine*, Ergonomics(Final Report, Task E), p.80.

Adams-Guppy, J. & Guppy, A., 2003. Truck driver fatigue risk assessment and management: a multinational survey. *Ergonomics*, 46(8), pp.763–779.

Aghazadeh, S.-M., 2003. A new mandate for operations managers. *Work Study*, 52(6), pp.310–316.

Åkerstedt, T. et al., 2008. Disturbed sleep in shift workers, day workers, and insomniacs. *Chronobiology International*, 25(2), pp.333–348.

Åkerstedt, T., 1998. Shift work and disturbed sleep/wakefulness. *Sleep Medicine Reviews*, 2(2), pp.117–128.

Alexander, J.A., 1991. Adaptive change in corporate control practices. *Academy of Management Journal*, 34(1), pp.162–193.

All Trucking, 2016. *Truck Drivers in the USA | AllTrucking.com*, Available at: http://www.alltrucking.com/faq/truck-drivers-in-the-usa/ [Accessed May 10, 2016].

American Trucking Association, 2016. *American Trucking Associations*, Available at: http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx [Accessed May 10, 2016].

Amorim, P., Günther, H.O. & Almada-Lobo, B., 2012. Multi-objective integrated production and distribution planning of perishable products. *International Journal of Production Economics*, 138(1), pp.89–101.

Anderson, J.E. et al., 2012. Obesity is associated with the future risk of heavy truck crashes among newly recruited commercial drivers. *PTW + Cognitive impairment and Driving Safety*, 49(0), pp.378–384.

Anderson, J.L., 1997. Government Suasion: Refocusing the Lowi Policy Typology. *Policy Studies Journal*, 25(2), p.266. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=f6h&AN=9711224475&site=ehost-live.

Anon, 2014. COMMERCE, JUSTICE, SCIENCE, AND RELATED AGENCIES APPROPRIATIONS ACT, 2015--MOTION TO PROCEED. , (2nd Session), pp.S3836–S3842. Available at: https://www.congress.gov/congressional-record/2014/6/19/senate-section/article/s3836-2.

Anon, 2016. Data | National Highway Traffic Safety Administration (NHTSA). Available at: http://www.nhtsa.gov/NCSA [Accessed February 26, 2016].

Anon, 2013. Executive Summary 2013 Independent Driver Survey | Recent Research | OOIDA Foundation. Available at: http://www.ooida.com/OOIDA Foundation/RecentResearch/HOSSurvey.asp [Accessed October 5, 2015].

Anon, 2000. Federal Register, Volume 65 Issue 85 (Tuesday, May 2, 2000). *FMSCA*. Available at: http://www.gpo.gov/fdsys/pkg/FR-2000-05-02/html/00-10703.htm [Accessed August 28, 2015].

Armon, R., 2013. Speed limit jumps to 70 mph Monday on Ohio interstates - Local - Ohio . , 2015(7/9/2015). Available at: http://www.ohio.com/news/local/speed-limit-jumps-to-70-mph-monday-on-ohio-interstates-1.409974.

Arnold, P.K. et al., 1997. Hours of work, and perceptions of fatigue among truck drivers. *Accident Analysis & Prevention*, 29(4), pp.471–477.

Arrow, K.J. et al., 1996. Is there a role for benefit-cost analysis in environmental, health, and safety regulation? *Science*, 272(5259), p.221. Available at: http://search.proquest.com/openview/2b04fbd2c1d49a147b3342345c803cab/1?pq-origsite=gscholar&cbl=1256 [Accessed February 5, 2016].

Bailey, K.D., 1994. *Typologies and Taxonomies. An introduction to classification techniques*,

Bakker, M., Riezebos, J. & Teunter, R., 2012. Review of inventory systems with deterioration since 2001. *European Journal of Operational*, 221(2), pp.275–284.

Barns, D., 2000. Proposal to Reignite Battle over Fatigue Research. *Transport Topics*, 33(80), pp.6–7.

Barton, A.H., 1955. The concept of property-space in social research. *The language of social research*, pp.40–53.

Beilock, R., 1995. Schedule-induced hours-of-service and speed limit violations among tractor-trailer drivers. *Accident Analysis & Prevention*, 27(1), pp.33–42.

Belzer, M.H. et al., 2014. *Logistics and Transportation*, Pennsylvania: Pennsylvania Workforce Development.

Blanco, M., Hanowski, R.J., Olson, R.L., et al., 2011. No Title. *The impact of driving, non-driving work, and rest breaks on driving performance in commercial motor vehicle operations*.

Blanco, M., Hanowski, R.J. & Olson, R.L., 2011. *The impact of driving, non-driving work, and rest breaks on driving performance in commercial motor vehicle operations. No. FMCSA-RRR-11-017*, Available at: http://trid.trb.org/view.aspx?id=1108816 [Accessed February 26, 2016].

Blower, D. & Campbell, K.L., 1998. *Fatalities and injuries in truck crashes by time of day*, Ann Arbor, Michigan.

Braver, E.R., Preusser, C.W. & Ulmer, R.G., 1999. How Long-Haul Motor Carriers Determine Truck Driver Work Schedules: The Role of Shipper Demands. *Journal of Safety Research*, 30(3), pp.193–204.

Brewster, R. & Short, J., 2014. *Assessment of the FMCSA Naturalistic Field Study on Hours-Of-Service Restart Provisions*,

Breyer, S., 1986. Judicial Review of Questions of Law and Policy. *Administrative Law Review*, 38(4), pp.363–393.

Broekmeulen, R.A. & Donselaar, K.H. van D., 2007. *A replenishment policy for a perishable inventory system based on estimated aging and retrieval behavior*,

Brown, I., 1986. Fatigue, safety and the truck driver. *Accident Analysis & Prevention*, 18(2), pp.178–179.

Bruning, E.R., 1989. The relationship between profitability and safety performance in trucking firms. *Transportation journal*, pp.40–49.

Bucklew, K.J., 2011. Improving Freight Roadway Transportation with Dedicated Truck Lanes: Opportunities and Issues. *Transportation Journal (Pennsylvania State University Press)*, 50(4), p.431.

Burns, L.D. & Hall, R.W., 1985. Distribution strategies that minimize transportation and inventory costs. *Operations Research*, 33(3), pp.469–490.

Campbell, J.F., 1995. Peak period large truck restrictions and a shift to off-peak operations:

Impact on truck emissions and performance. *Journal of Business Logistics*, 16(2), p.227.

Cantor, D.E. et al., 2010. A driver focused truck crash prediction model. *Transportation Research: Part E*, 46(5), pp.683–692.

Cantor, D.E., Corsi, T.M. & Grimm, C.M., 2009. Do Electronic Logbooks Contribute to Motor Carrier Safety Performance? *Journal of Business Logistics*, 30(1), pp.203–222.

Chang, L.-Y. & Chien, J.-T., 2013. Analysis of driver injury severity in truck-involved accidents using a non-parametric classification tree model. *Safety Science*, 51(1), pp.17–22.

Chen, C. & Xie, Y., 2014a. Modeling the safety impacts of driving hours and rest breaks on truck drivers considering time-dependent covariates. *Journal of Safety Research*, 51(0), pp.57–63.

Chen, C. & Xie, Y., 2014b. The impacts of multiple rest-break periods on commercial truck driver's crash risk. *Journal of Safety Research*, 48(0), pp.87–93.

Chen, G.X. et al., 2015. NIOSH national survey of long-haul truck drivers: Injury and safety. *Accident Analysis and Prevention*, 85, pp.66–72.

Chen, S., Chen, F. & Wu, J., 2011. Multi-scale traffic safety and operational performance study of large trucks on mountainous interstate highway. *Accident Analysis & Prevention*, 43(1), pp.429–438. Available at: http://www.sciencedirect.com/science/article/pii/S0001457510002769.

Cohen--Mansfield, J. & Werner, P., 1997. Typology of disruptive vocalizations in older persons suffering from dementia. *International Journal of Geriatric Psychiatry*, 12(11), pp.1079–1091.

Craft, R. & Blower, D., 2004. The large truck crash causation study. *Paper presented and distributed at the November*, 17, p.2004.

Crouch, D.J. et al., 1993. The prevalence of drugs and alcohol in fatally injured truck drivers. *Journal of forensic sciences*, 38(6), pp.1342–1353.

Crum, M. & Morrow, P., 2002. The influence of carrier scheduling practices on truck driver fatigue. *Transportation Journal*. Available at: http://www.jstor.org/stable/20713513 [Accessed October 16, 2015].

Crum, M.R. & Morrow, P.C., 2002. The Influence of Carrier Scheduling Practices on Truck Driver Fatigue. *Transportation Journal (American Society of Transportation & Logistics Inc)*, 42(1), p.20.

DeLeo, R.A., 2015. *Anticipatory Policymaking: When Government Acts to Prevent Problems and Why It Is So Difficult*, Routledge.

Dinges, D.F., 1995. An overview of sleepiness and accidents. *Journal of sleep research*, 4(S2), pp.4–14.

Dingus, T.A. et al., 2006. The development of a naturalistic data collection system to perform critical incident analysis: An investigation of safety and fatigue issues in long-haul trucking. *Accident Analysis & Prevention*, 38(6), pp.1127–1136.

Van Dongen, H. & Mollicone, D., 2014. *Field Study on the Efficacy of the New Restart Provision for Hours of Service*, Washingont, DC: Department o fTransportations.

Dongen, V. & Dinges, D.F., 2005. Circadian rhythms in sleepiness, alertness, and performance. *Principles and Practice of Sleep Medicine*, 4, pp.435–43. Available at: http://faculty.vet.upenn.edu/uep/user_documents/dfd20.pdf [Accessed February 17, 2016].

Douglas, M.A. & Swartz, S.M., 2009. A multi-dimensional construct of commercial motor vehicle operators' attitudes toward safety regulations. *Int Jrnl Logistics Management*, 20(2), pp.278–293.

Downs, A., 1992. *Stuck in traffic: Coping with peak-hour traffic congestion*,

Drescher, S.R. et al., 2011. Research and Policy Implications for Watershed Management in the Atlantic Coastal Plain. *Coastal Management*, 39(3), pp.242–258. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=60122801&site=ehost-live.

Duke, J., Guest, M. & Boggess, M., 2010. Age-related safety in professional heavy vehicle drivers: A literature review. *Accident Analysis & Prevention*, 42(2), pp.364–371.

Duncan, C., Khattak, A. & Council, F., 1998. Applying the ordered probit model to injury severity in truck-passenger car rear-end collisions. *Trasportation Research Record: Journal: Journal of Transportation Research Board*, 1635, pp.63–71.

Eisele, B., Schrank, D. & Lomax, T., 2011. Congested Corridors Report. *Texas Transportation Institute, Appendix B B-3*.

Engau, C. & Hoffmann, V.H., 2011. Strategizing in an unpredictable climate: exploring corporate strategies to cope with regulatory uncertainty. *Long Range Planning*, 44(1), pp.42–63.

Federal Motor Carrier Safety Administration, 1995. *Department Of Transportation: Federal*

Highway Administration: Rules and Regulations: Zero Base Review of the Federal Motor Carrier Safety Regulations; Correcting Amendments: [FR DOC # 95-18382],

Federal Motor Carrier Safety Administration, 2000. *Department Of Transportation: Federal Motor Carrier Safety Administration: Proposed Rules: Hours of Service of Drivers; Driver Rest and Sleep for Safe Operations: [FR DOC # 00-10703]*, Department of Transportations.

Federal Motor Carrier Safety Administration, 2003. *Department Of Transportation: Federal Motor Carrier Safety Administration: Rules and Regulations: Hours of Service of Drivers; Driver Rest and Sleep for Safe Operations: [FR DOC # 03-9971]*,

Federal Motor Carrier Safety Administration, 2011. *Department of Transportation: Final Rule: Hours of Service of Drivers: [FR DOC # 2011-81134]*,

Federal Motor Carrier Safety Administration, 2016. Hours of Service | Federal Motor Carrier Safety Administration. *Department of Transportation*. Available at: https://www.fmcsa.dot.gov/regulations/hours-of-service [Accessed February 16, 2016].

Fender, K.J. & Pierce, D.A., 2013. *An Analysis of the Operational Costs of Trucking: 2013 Update*, Arlington, Virginia: ATRI. Available at: http://truckexec.typepad.com/files/atri-operational-costs-of-trucking-2013-final.pdf.

Ferro, H.A., 2014. *Wrong Way: The Impact of FMSCA's Hours of Service Regulation on Small Businesses*, Washington DC: U.S. Government Printing Office. Available at: http://www.gpo.gov/fdsys/pkg/CHRG-113hhrg85596/html/CHRG-113hhrg85596.htm.

FHWA Docket No. MC-128, V. 53 p. 39044, 1988. *Department Of Transportation: Federal Transit Administration: Summary of the BAC Level Provisions of the Act [FR DOC # 88-39044]*,

Figliozzi, M.A., 2011. The impacts of congestion on time-definitive urban freight distribution networks CO2 emission levels: Results from a case study in Portland, Oregon. *Transportation Research Part C: Emerging Technologies*, 19(5), pp.766–778.

Fitzsimmons, J.A., 1985. Consumer participation and productivity in service operations. *Interfaces*, 15(3), pp.60–67.

Fitzsimmons, J.A., Fitzsimmons, M. & Bordoloi, S., 2013. *Service management: operations, strategy, and information technology* 8th ed.,

Fleiss, J.L.., 1973. *Statistical methods for rates and proportions*,

FMSCA, 2010. 2010-

2011_Hours_of_Service_Rule_Regulatory_Impact_Analysis_for_the_Proposed_Hours_of_Service_(HOS)_of_Drivers_Rule,_December_20,_2010_(1).pdf. , p.119. Available at: http://www.regulations.gov/#!documentDetail;D=FMCSA-2004-19608-4116.

FMSCA, 2015. Hours of Service. , 2014(February/5). Available at: http://www.fmcsa.dot.gov/rules-regulations/topics/hos/index.htm.

Folkard, S. & Tucker, P., 2003. Shift work, safety and productivity. *Occupational medicine*, 53(2), pp.95–101.

Forkenbrock, D.J., 1999. External costs of intercity truck freight transportation. *Transportation Research Part A: Policy and Practice*, 33(7), pp.505–526.

Friswell, R. & Williamson, A., 2013. Comparison of the fatigue experiences of short haul light and long distance heavy vehicle drivers. *Safety Science*, 57(0), pp.203–213. Available at: http://www.sciencedirect.com/science/article/pii/S0925753513000623.

Gander, P.H. et al., 2006. Investigating driver fatigue in truck crashes: Trial of a systematic methodology. *Transportation Research Part F: Traffic Psychology and Behaviour*, 9(1), pp.65–76. Available at: http://www.sciencedirect.com/science/article/pii/S1369847805000720.

Goel, A., 2014. Hours of service regulations in the United States and the 2013 rule change. *Transport Policy*, 33(0), pp.48–55.

Golias, M., 2015. *EVALUATING THE HOURS-OF-SERVICE RULE VIA GPS/GIS TRUCK TRIP DATA*, Available at: https://wwwnew.memphis.edu/ifti/pdfs/cifts_evaluating_hours_of_service.pdf [Accessed August 12, 2015].

Gordon, T.J., 1994. *Trend impact analysis*,

Goyal, S. & Giri, B., 2001. Recent trends in modeling of deteriorating inventory. *European Journal of operational research*, 164(1), pp.1–16.

Grant, A., 2013. Speed limits increase on some Ohio roadways | cleveland.com. *Advance Digital*, p.2. Available at: http://www.cleveland.com/metro/index.ssf/2013/09/speed_limits_increase_on_some.html.

Grewal, M.S. & Andrews, A.P., 2014. *Kalman filtering: Theory and Practice with MATLAB*, John Wiley & Sons.

Griffin, G.C., Rodriguez, J. & Lantz, B.M., 1992. *Evaluation of the Impact of Changes in the*

Hours of Service Regulations on Efficiency, Drivers and Safety.

Grugle, N., 2014. Asleep at the Wheel: Sleep Deprivation and Fatigue in Commercial Trucking. *Human Factors & Ergonomics*, p.2. Available at: http://www.robsonforensic.com/articles/asleep-at-the-wheel-sleep-deprivation-and-fatigue-in-commercial-trucking [Accessed October 7, 2015].

Hahm, J. & Yano, C.A., 1995. The economic lot and delivery scheduling problem: the common cycle case. *IIE transactions*, 27(2), pp.113–125.

Hall, R.W. & Mukherjee, A., 2008. Bounds on effectiveness of driver hours-of-service regulations for freight motor carriers. *Selected Papers from the National Urban Freight Conference*, 44(2), pp.298–312.

Hanowski, R. et al., 2011. Long-haul truck driving and traffic safety: studying drowsiness and truck driver safety using a naturalistic driving method. *... and traffic safety. NY: Nova Science ...*. Available at: https://scholar.google.com/scholar?q=blanco+2011+truck&hl=en&as_sdt=0%2C36&as_ylo=2011&as_yhi=#0 [Accessed February 26, 2016].

Hanowski, R.J. et al., 2009. Evaluating the 2003 revised hours-of-service regulations for truck drivers: The impact of time-on-task on critical incident risk. *Accident Analysis & Prevention*, 41(2), pp.268–275.

Hanowski, R.J. et al., 2007. The sleep of commercial vehicle drivers under the 2003 hours-of-service regulations. *Accident Analysis & Prevention*, 39(6), pp.1140–1145. Available at: http://www.sciencedirect.com/science/article/pii/S0001457507000310.

Hanowski, R.J., Perez, M.A. & Dingus, T.A., 2005. Driver distraction in long-haul truck drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(6), pp.441–458.

Harris, W., 1977. Fatigue, circadian rhythm, and truck accidents. In *Vigilance*. Springer, pp. 133–146.

Hartley, L.R. & Hassani, J. El, 1994. Stress, violations and accidents. *Applied Ergonomics*, 24(4), pp.221–230.

Hertz, R.P., 1988. Tractor-trailer driver fatality: The role of nonconsecutive rest in a sleeper berth. *Accident Analysis & Prevention*, 20(6), pp.431–439.

Holcomb, M.C., Liao-Troth, S. & Manrodt, K.B., 2014. A Shift in Fundamentals: The Changing Direction in Logistics and Transportation Management. *Transportation Journal*, 53(4), pp.516–533.

Hollander, M., Wolfe, D.A. & Chicken, E., 2013. *Nonparametric statistical methods*,

Horne, J.A. & Burley, C. V, 2010. We know when we are sleepy: Subjective versus objective measurements of moderate sleepiness in healthy adults. *Biological psychology*, 83(3), pp.266–268.

Horne, J.A. & Reyner, L., 1995. Driver sleepiness. *Journal of sleep research*, 4(s2), pp.23–29.

Itti, S. & Gokak, V., 2013. Optimization of Steel Sections Using Genetic Algorithms and Exhaustive Enumerative Methods. *IUP Journal of Structural Engineering*, 6(1), p.32.

Jensen, A. & Dahl, S., 2009. Truck drivers hours-of-service regulations and occupational health. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 33(3), pp.363–368.

Jo Bitner, M. et al., 1997. Customer contributions and roles in service delivery. *International journal of service industry management*, 8(3), pp.193–205.

Joshua, S.C. & Garber, N.J., 1990. Estimating truck accident rate and involvements using linear and Poisson regression models. *Transportation planning and Technology*, 15(1), pp.41–58.

Jovanis, P.P. & Chang, H.-L.L., 1986. Modeling the relationship of accidents to miles traveled. *Transportation Research Record*, (1068), pp.42–51.

Jovanis, P.P., Wu, K.-F.F. & Chen, C., 2011. *Hours of service and driver fatigue: Driver characteristics research. No FMSCA-RRR-11-018*,

Kahane, C.J., 2015. Lives Saved by vehicle safety technologies and associated federal motor vehicle safety standards, 1960 to 2012 passenger cars and LTVs with reviews of 26. In *24th Technical Conference on the Enhance Safety of Vehicles*. Gothenburg, Sweden, p. 21.

Kahane, C.J., 1997. *Relationships between vehicle size and fatality risk in model year 1985-93 passenger cars and light trucks*, Available at: http://trid.trb.org/view.aspx?id=707395 [Accessed March 7, 2016].

Kaneko, T. & Jovanis, P.P., 1992. Multiday driving patterns and motor carrier accident risk: A disaggregate analysis. *Accident Analysis & Prevention*, 24(5), pp.437–456.

Kanlayasiri, K. & Boonmung, S., 2007. An investigation on effects of wire-EDM machining parameters on surface roughness of newly developed DC53 die steel. *3rd International Conference on Advanced Forming and Die Manufacturing Technology*, 187–188(0), pp.26–29.

Kemp, E., Kopp, S.W. & Kemp, E.C., 2013. Take This Job and Shove It: Examining the Influence of Role Stressors and Emotional Exhaustion on Organizational Commitment and Identification in Professional Truck Drivers. *Journal of Business Logistics*, 34(1), pp.33–45. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=86178369&site=ehost-live.

Kettinger, W.J., Patel, J.M. & Ryoo, S.Y., 2012. *The Role of Information Technology in Causing and Reducing Truck Driver Stress and its Relationship to Turnover*, Available at: http://lcmsstaging.memphis.edu/ifti/pdfs/cifts_truck_driver_stress.pdf [Accessed August 11, 2015].

Khasnabis, S. & Ramiz-Al-Assar, 1989. Analysis of Heavy Truck Accident Data-Exposure Based Approach. *Journal of transportation Transportation Engineering*, 115(3), pp.298–304. Available at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-947X(1989)115:3(298) [Accessed March 4, 2016].

Khattak, A.J., Schneider, R.J. & Targa, F., 2003. *Risk factors in large truck rollovers and injury severity: analysis of single-vehicle collisions*,

Kimes, S.E., 1989. Yield management: A tool for capacity-considered service firms. *Journal of Operations Management*, 8(4), pp.348–363.

Kishore, R.A. et al., 2011. N-Period Dynamic Deterministic Inventory Model for Perishable Goods. *IUP Journal of Operations Management*, 10(1).

Kluge, S., 2000. Empirically grounded construction of types and typologies in qualitative social research. *Forum Qualitative Qualitative Social Research*, 1(1).

Kok, A.L., Hans, E. & Schutten, J., 2012. Vehicle routing under time-dependent travel times: the impact of congestion avoidance. *Computers & Operations Research*, 39(5), pp.910–918.

Kononov, J., Bailey, B. & Allery, B., 2008. Relationships between safety and both congestion and number of lanes on urban freeways. *Transportation Research Record: Journal of the Transportation Research Board*, (2083), pp.26–39.

Landis, R.J. & Koch, G.G., 1977. The measurement of observer agreement for categorical data. *biometrics*, March, pp.159–174. Available at: http://www.jstor.org/stable/2529310 [Accessed April 21, 2016].

Lavie, P., 1986. Ultrashort sleep-waking schedule. III.’Gates' and “forbidden zones” for sleep. *Electroencephalography and clinical neurophysiology*, 63(5), pp.414–425.

Levene, H., 1960. Robust tests for equality of variances1. *Contributions to probability and statistics: Essays in honor of Harold Hotelling*, 2, pp.278–292.

Liao, C.-J. & Chih-Hsiung, S., 1991. An analytical determination of lead time with normal demand. *International Journal of Operations & …*, 11(9), pp.72–78.

Lindblom, C.E., 1959. The science of" muddling through." *Public administration review*, (April 1), pp.79–88.

Lowi, T.J., 1964. American business, public policy, case-studies, and political theory. *World politics*, 16(4), pp.677–715.

Lowi, T.J., 1972. Four systems of policy, politics, and choice. *Public administration review*, pp.298–310.

Luo, Y., 2004. Building a Strong Foothold in an Emerging Market: A Link Between Resource Commitment and Environment Conditions*. *Journal of Management Studies*, 41(5), pp.749–773.

Lyman, S. & Braver, E.R., 2003. Occupant deaths in large truck crashes in the United States: 25 years of experience. *Accident Analysis & Prevention*, 35(5), pp.731–739.

Macchi, M.M. et al., 2002. Effects of an afternoon nap on nighttime alertness and performance in long-haul drivers. *Accident Analysis & Prevention*, 34(6), pp.825–834.

Mackie, R.R. & Miller, J.C., 1978. *Effects of Hours of Service Regularity of Schedules and Cargo Loading on Truck and Bus Driver Fatigue*,

Marcus, A. & Kaufman, A., 1986. Why it is difficult to implement industrial policies: Lessons from the synfuels experience. *California Management Review*. Available at: http://cmr.ucpress.edu/content/28/4/98.abstract [Accessed September 18, 2015].

Margolin, J., Candea, B. & Schabner, D., 2014. Truck Driver Charged With Causing Crash That Injured Tracy Morgan. *ABC Good Morning America*. Available at: http://abcnews.go.com/Entertainment/truck-driver-charged-causing-crash-injured-tracy-morgan/story?id=24039407.

Martinez, R., 1997. *Traffic Safety Facts (1996): A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*, DIANE Publishing.

McCartt, A.T. et al., 2000. Factors associated with falling asleep at the wheel among long-distance truck drivers. *Accident Analysis & Prevention*, 32(4), pp.493–504.

McClelland, J.C., 2013. *A NEW BASELINE FOR CHRONIC FATIGUE: WHY MEASURING FLIGHT TIME IS THE WRONG APPROACH*. Air University.

McCorry, B. & Murray, W., 1993. Reducing commercial vehicle road accident costs. *International Journal of Physical Distribution & Logistics Management*, 23(4), pp.35–41.

McGwin Jr, G. & Brown, D.B., 1999. Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis & Prevention*, 31(3), pp.181–189.

McKinnon, A., 2006. Life without trucks: The impact of a temporary disruption of road freight transport on a national economy. *Journal of Business Logistics*, 27(2), pp.227–250.

McKnight, J.A. & Bahouth, G.T., 2009. Analysis of large truck rollover crashes. *Traffic injury prevention*, 10(5), pp.421–426.

Miller, J.W. & Saldanha, J.P., 2013. Combining formal controls to improve firm performance. *Journal of Business Logistics*, 34(1), pp.301–318.

Miller, T. et al., 1991. *THE COSTS OF HIGHWAY CRASHES. FINAL REPORT*,

Min, H., 2009a. Combined Truck Routing and Driver Scheduling Problems under Hours of Service Regulations.

Min, H., 2009b. The impact of hours-of-service regulations on transportation productivity and safety: A summary of findings from the literature. *Journal of Transportation Management*, 21(2).

Mitchell, D.E., Marshall, C. & Wirt, F.M., 1985. Building a taxonomy of state education policies. *Peabody Journal of Education*, 62(4), pp.7–47.

Mitler, M.M. et al., 1997. The sleep of long-haul truck drivers. *New England Journal of Medicine*, 337(11), pp.755–762.

Montague, M., 2014. Tough Timing New Hours of sercie rules are affecting porductivity and rates. *Trucking Trends*, p.12. Available at: http://digital.nexsitepublishing.com/i/269434/11.

Montgomery, J.D., 1990. Environmental management as a third-world problem. *Policy Sciences*, 23(2), pp.163–176. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=16858355&site=ehost-live.

Moonesinghe, R. et al., 2003. *An analysis of fatal large truck crashes*, Morrow, P.C. & Crum, M.R., 2004. Antecedents of fatigue, close calls, and crashes among commercial motor-vehicle drivers. *Journal of Safety Research*, 35(1), pp.59–69.

Murray, D.C. & Short, J., 2015. *Technical Memorandum Quantifying Impacts from the 34-Hour Restart Provisions*, Available at: http://atri-online.org/wp-content/uploads/2015/04/Quantifying-Impacts-from-34-hr-Restart-Provision-FINAL-04-2015.pdf.

Nahmias, S., 1974. Inventory Depletion Management when the Field Life is Random. *Management Science*, 20(9), pp.1276–1283.

Nahmias, S., 1975. Optimal ordering policies for perishable inventory—II. *Operations research*, 23(4), pp.735–749.

Nahmias, S., 1982. Perishable inventory theory: A review. *Operations research*, 30(4), pp.680–708.

Nahmias, S. & Pierskalla, W.P., 1976. A two-product perishable/nonperishable inventory problem. *SIAM Journal on Applied Mathematics*, 30(3), pp.483–500.

Neeley, G.W. & Richardson, L.E., 2009. The effect of state regulations on truck-crash fatalities. *American journal of public health*, 99(3), p.408.

Newman, P.W.G. & Kenworthy, J.R., 1989. Gasoline consumption and cities: a comparison of US cities with a global survey. *Journal of the American Planning Association*, 55(1), pp.24–37.

NHTSA, 2015. Traffic Safety Facts: Large Trucks. *NHTSA*, p.2015. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/812150.pdf [Accessed October 27, 2015].

Nicoletti, G. & Scarpetta, S., 2003. Regulation, productivity and growth: OECD evidence. *Economic Policy*, 18(36), pp.9–72.

NTSB, 1990. *National Transportation Safety Board. Safety Study: Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes*,

Olson, R.L. et al., 2009. *Driver distraction in commercial vehicle operations*, Available at: http://trid.trb.org/view.aspx?id=907078 [Accessed October 13, 2015].

Paddock, R.D., 1974. The traffic conflicts technique: an accident prediction method. *Transportation research record*, 486, pp.1–10.

Patton, O., 2014. Senate Panel Votes to Suspend Hours of Service Restart Pending Study. *Fleet Management*, p.4. Available at: http://www.truckinginfo.com/channel/fleet-management/news/story/2014/06/senate-.

Peeta, S., Zhang, P. & Zhou, W., 2005. Behavior-based analysis of freeway car–truck interactions and related mitigation strategies. *Transportation Research Part B: Methodological*, 39(5), pp.417–451.

Philip, P., Taillard, J. & Moore, N., 2006. The effects of coffee and napping on nighttime highway driving: a randomized trial. *Annals of Internal …*, 144(11), pp.785–791.

Plungis, J. & Voreacos, D., 2014. Droopy Eyelid Detector One Solution to Truck Crashes. *Bloomberg*, p.2. Available at: http://www.bloomberg.com/news/2014-10-07/droopy-eyelid-detector-one-solution-to-truck-crashes.html.

Pritchard, R.D., 2010. *Federal motor carrier safety policy: reducing fatalities with increased financial responsibility*, NorthEastern University.

Pritchard, R.D., 2010. *Federal motor carrier safety policy: reducing fatalities with increased financial responsibility*. NorthEastern University.

Pyke, A., 2014. The Link Between Tracy Morgan's Tragic Accident And Trucker Pay | ThinkProgress. *Think Progress*. Available at: http://thinkprogress.org/economy/2014/09/10/3565820/tracy-morgan-truck-driver-pay-regulations/ [Accessed October 11, 2015].

Quan, C. et al., 2015. Brief Review : Sleep Health and Safety for Transportation Workers. *SOuthwest Journal of Pulmonary and Critical Care*, 10(3), pp.130–9.

Razali, N.M. & Wah, Y.B., 2011. Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. *Journal of Statistical Modeling and Analytics*, 2(1), pp.21–33.

Retzer, K.D., Hill, R.D. & Pratt, S.G., 2013. Motor vehicle fatalities among oil and gas extraction workers. *Accident Analysis & Prevention*, 51, pp.168–174.

Rio-Bermudez, C. Del et al., 2014. Chronotype-dependent circadian rhythmicity of driving safety. *Chronobiology Internation*, 31(4), pp.532–541.

Rodriguez, D.A., Targa, F. & Belzer, M.H., 2006. Pay incentives and truck driver safety: a case study. *Industrial & Labor Relations …*, 59(2), pp.205–225.

Rogerson, W.P., 1992. Overhead allocation and incentives for cost minimization in defense procurement. *Accounting Review*, pp.671–690.

Rothaermel, F.T. & Hill, C.W., 2005. Technological discontinuities and complementary assets: A longitudinal study of industry and firm performance. *Organization Science*, 16(1), pp.52–70.

Roy, A., Kar, S. & Maiti, M., 2010. A volume flexible production-policy for randomly deteriorating item with trended demand and shortages. *International Journal of Production Economics*, 128(1), pp.188–199.

Rugman, A.M. & Verbeke, A., 1998. Corporate strategy and international environmental policy. *Journal of International Business Studies*, December(1), pp.819–833. Available at: http://www.jstor.org/stable/155411 [Accessed September 2, 2015].

Saccomanno, F. & Nassar, S., 1997. Geographic information system platform for road accident risk modeling. *Transportation Research Record: Journal of the Trasportation Research Board*, (1581), pp.18–265.

Salomon, I. & Mokhtarian, P.L., 1997. *University of California Transportation University of California*,

Sando, T., Mtoi, E. & Moses, R., 2010. *Potential Causes of Driver Fatigue: A Study on Transit Bus Operators in Florida*,

Sándor, Z.P. & Csiszár, C., 2013. Development Stages of Intelligent Parking Information Systems for Trucks. *Acta Polytechnica Hungarica*, 10(4).

Schane, S., 2002. Ambiguity and Misunderstanding in the Law. *Thomas Jefferson Law Review*, 25, pp.167–182.

Schneider, A. & Sidney, M., 2009. What Is Next for Policy Design and Social Construction Theory? *Policy Studies Journal*, 37(1), pp.103–119.

Schneider, A.L. & Ingram, H.M., 1997. *Policy design for democracy*, University Press of Kansas Lawrence, KS.

Sengupta, K., Heiser, D.R. & Cook, L.S., 2006. Manufacturing and service supply chain performance: a comparative analysis. *Journal of Supply Chain Management*, 42(4), pp.4–15.

Shibuya, H., Cleal, B. & Kines, P., 2010. Hazard scenarios of truck drivers' occupational accidents on and around trucks during loading and unloading. *Accident Analysis & Prevention*, 42(1), pp.19–29.

Short, J., 2013. Operational and Economic Impacts of the New Hours-of-Service.

Short, J. & Murray, D.C., 2014. *Congestion Impact Analysis of Freight-Significant Highway Locations 2014*,

Siferd, S.P., Benton, W.C. & Ritzman, L.P., 1992. Strategies for service systems. *European Journal of Operational Research*, 56(3), pp.291–303.

Siriruk, P., 2012. The Optimal Ordering Policy for a Perishable Inventory System. In *Proceedings of the World Congress on Engineering and Computer Science*.

Smith, K.B., 2002. Typologies, taxonomies, and the benefits of policy classification. *Policy Studies Journal*, 30(3), pp.379–395.

Soccolich, S.A. et al., 2013. An analysis of driving and working hour on commercial motor vehicle driver safety using naturalistic data collection. *Accident Analysis & Prevention*, 58(0), pp.249–258.

Solomon, D., 1964. Accidents on main rural highways related to speed, driver, and vehicle. *Transportation Research Board*, p.44. Available at: http://trid.trb.org/view.aspx?id=1186988 [Accessed February 26, 2016].

Staplin, L. & Gish, K.W., 2005. Job change rate as a crash predictor for interstate truck drivers. *Accident Analysis & Prevention*, 37(6), pp.1035–1039.

Stecke, K.E. & Kumar, S., 2009. Sources of supply chain disruptions, factors that breed vulnerability, and mitigating strategies. *Journal of Marketing Channels*, 16(3), pp.193–226.

Stoohs, R.A. et al., 1994. Traffic accidents in commercial long-haul truck drivers: the influence of sleep-disordered breathing and obesity. *SLEEP-NEW YORK-*, 17, p.619.

Summala, H. & Mikkola, T., 1994. Fatal accidents among car and truck drivers: effects of fatigue, age, and alcohol consumption. *Human Factors: The Journal of the …*, 36(2), pp.315–326.

Taylor, A.H. & Dorn, L., 2006. Stress, fatigue, health, and risk of road traffic accidents among professional drivers: the contribution of physical inactivity. *Annu. Rev. Public Health*, 27, pp.371–391.

The American Automobile Association Foundation for Traffic Safety, 1985. *A report on the determination and evaluation of the role of fatigue in heavy truck accidents*,

Tikriti, A., 2015. Driver vs. Company Liability in Commercial Truck Accidents - AllLaw.com. Available at: http://www.alllaw.com/articles/nolo/auto-accident/liability-commercial-truck-accident.html [Accessed September 3, 2015].

Tommelein, I.D. & Li, A., 1999. Just-in-time concrete delivery: mapping alternatives for vertical supply chain integration. *Proceedings IGLC*, 7, p.97.

Torregroza-Vargas, N.M., Bocarejo, J.P. & Ramos-Bonilla, J.P., 2014. Fatigue and crashes: The case of freight transport in Colombia. *Accident Analysis & Prevention*, 72(0), pp.440–448.

Towns, D.M. & Cobb, L.M., 2012. Notes on: GPS technology; Employee monitoring enters a new era. *Labor Law Journal*, 63(3), p.203.

US Census Bureau, 2015. *2012 Commodity Flow Survey*, Available at: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/ec12tcf-us.pdf.

Veenhoven, R., 2002. Why social policy needs subjective indicators. *Social Indicators Research*, 58(1-3), pp.33–46.

Vogt, A. & Bared, J., 1998. Accident models for two-lane rural segments and intersections. *Transportation Research Record: Journal of the transportation Research Board*, (1635), pp.18–29.

Wang, F. & McDonald, T., 2004. Relationship of body mass index and physical activity to health care costs among employees. *... of Occupational and ...*, 46(5), pp.428–436.

Weatherford, L.L.R. & Bodily, S.E.S., 1992. A taxonomy and research overview of perishable-asset revenue management: yield management, overbooking, and pricing. *Operations research*, 40(5), pp.831–844.

Wiegand, D.M., Hanowski, R.J. & McDonald, S.E., 2009. Commercial drivers' health: a naturalistic study of body mass index, fatigue, and involvement in safety-critical events. *Traffic injury prevention*, 10(6), pp.573–579.

Williams, L.R., Davies, D.R. & Thiele, K., 2012. Young drivers' perceptions of culpability of sleep-deprived versus drinking drivers. *Journal of safety ...*, 43(2), pp.115–122.

Williamson, A. et al., 2011. The link between fatigue and safety. *Advancing Fatigue and Safety Research*, 43(2), pp.498–515.

Williamson, A. & Friswell, R., 2013. The effect of external non-driving factors, payment type and waiting and queuing on fatigue in long distance trucking. *Accident Analysis & Prevention*, 58(0), pp.26–34.

Williamson, A.M. et al., 1992. *Strategies to combat fatigue in the long distance road transport industry. Stage 1: The industry perspective*,

Williamson, A.M., Feyer, A.-M. & Friswell, R., 1996. The impact of work practices on fatigue in long distance truck drivers. *Accident Analysis & Prevention*, 28(6), pp.709–719.

Woensel, T. Van et al., 2007. Consumer responses to shelf out-of-stocks of perishable products. *International Journal of Physical Distribution & Logistics Management*, 37(9), pp.704–718.

Yeh, R.H., Kao, K.-C. & Chang, W.L., 2009. Optimal preventive maintenance policy for leased equipment using failure rate reduction. *Computers & Industrial Engineering*, 57(1), pp.304–309.

Young, K., Regan, M. & Hammer, M., 2007. Driver distraction: A review of the literature. *Distracted driving Australasian College of Road Safety*, pp.379–405. Available at: http://acrs.org.au/files/papers/15 Young A review of the literature.pdf [Accessed February 26, 2016].

Zhu, X. & Srinivasan, S., 2011. A comprehensive analysis of factors influencing the injury severity of large-truck crashes. *Accident Analysis & Prevention*, 43(1), pp.49–57.

Zohar, D. et al., 2014. A mediation model linking dispatcher leadership and work ownership with safety climate as predictors of truck driver safety performance. *Accident Analysis & Prevention*, 62(0), pp.17–25.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704–0188

1. REPORT DATE (DD–MM–YYYY)	2. REPORT TYPE	3. DATES COVERED (*From* — *To*)
17-09-2016	Dissertation	Aug 2013 – Sep 2016

4. TITLE AND SUBTITLE
An Examination of Commercial Motor Vehicle Hours of Service Safety Regulation

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Anderson, Jason R., Lt Col, USAF

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way, Building 640
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT-ENS-DS-16-S-25

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution Statement A. Approved For Public Release; Distribution Unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Federal Motor Carrier Safety Administration (FMSCA) stipulates Hours of Service (HOS) regulations in order to minimize or eliminate fatigued truck driving, a major cause of truck-related accidents. This research examines the efficacy of HOS with three unique research approaches: 1) a typology classification model to indicate differences in HOS regulation from other safety regulations, 2) an exhaustive enumeration method utilizing the theoretical foundation of perishable inventory theory, and 3) a statistical analysis on accidents caused by or involving truck drivers. This research provides insight into similar Air Force Instructions regarding flight-time restrictions for pilots, which attempt to prevent flying while fatigued. This research demonstrates that these types of restrictions do not directly measure fatigue and that they are subject to various unintended consequences.

15. SUBJECT TERMS
Hours of Service, Safety in Commercial Motor Vehicles, Fatigue, Enumeration, Perishable Inventory Theory

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Jeffrey Ogden, AFIT/ENS
U	U	U	UU	167	19b. TELEPHONE NUMBER (Include Area Code) (937) 255-6565, ext 4653 Jeffrey.ogden@afit.edu

Standard Form 298 (Rev. 8–98)
Prescribed by ANSI Std. Z39.18